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NITROGEN REMOVAL IN SUB-SURFACE FLOW CONSTRUCTED WETLANDS: INFLUENCE OF MIXED VEGETATION

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ABSTRACT

Excessive nitrogenous compounds entering into water environment due to improper wastewater dischargers, can lead to ecological changes in natural water bodies and various public health issues to water consumers. Constructed wetlands (CWs) are gaining popularity in many parts of the world for treating an array of wastewater pollutants, including nitrogenous compounds, due to their lower investment and operation costs while providing higher treatment efficiency with ecological benefits, over the conventional technologies. This study evaluated the influence of mixed vegetation on removal of nitrogenous compounds from wastewater, using laboratory scale sub-surface batch flow CWs, using two plant species; narrow-leaf cattail (*Typhaangustifolia*) and umbrella palms (*Cuperusalternifolius*). Twelve wetland units of size 0.5 m x 0.66 m (Diameter x Height) were prepared using 10-20 mm gravel as the wetland media and planted with two plants in each unit; four units with narrow-leaf cattail, four units with umbrella palms and the remaining four units with both plant species. Wastewater feeding was carried out batch wise at seven-day interval for three months. Wastewater samples were collected from the influent and effluents of each wetland unit at every seven-day interval and chemical oxygen demand (COD), Total nitrogen (TN), Nitrate nitrogen (NO_3^--N), Ammonia nitrogen (NH_3-N), pH, Electrical conductivity (EC) and temperature (T) were measured. Results showed that NH_3-N and TN removal in umbrella palm wetland units was higher ($p < 0.05$) than Cattail and mixed vegetation wetland units. Also, results revealed that mixed vegetation had no effect on nitrogen removal in sub-surface batch flow constructed wetlands.

KeyWords: Constructed wetlands, Nitrogen removal, Mixed vegetation, Sub-surface flow, Synthetic wastewater

INTRODUCTION

Degradation of natural water bodies due to discharge of inadequately treated wastewater is a major global problem, causing death and diseases to millions of people worldwide. Excessive nitrogen loading in water environment due to various anthropogenic activities can stimulate the growth of algae in water bodies leading to 'eutrophication', be toxic to aquatic species, deplete the dissolved oxygen (DO) concentration in the receiving waters etc.[1-3] has become major concerns in many countries.

Constructed wetlands (CW) are an artificial or engineered technique which mimics processes found in natural wetlands. They have been identified as an effective alternative for conventional wastewater treatment techniques due to their simple operation, low cost, efficient and robust treatment associated with ecological benefits. Also, they have been proven to be effective in removing many wastewater pollutants including nitrogenous compounds through an array of complex physical, chemical and biological processes by interaction of microbial communities, wetland plants, wetland media and water column[3-5]. Further, they are believed to be suitable for tropical regions as performances are expected to be better with elevated temperatures, longer sun shine hours and associated higher microbial activities[4].

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Among various nitrogen groups, dissolved inorganic nitrogen species such as nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_3) or ammonium (NH_4^+) have greater impact in aquatic systems since they are readily available for uptake by microorganisms than particulate organic nitrogen[3]. In CWs nitrogen removal happens through various complex processes including volatilization, ammonification, nitrification, de-nitrification, settling, plant uptake, microbial decomposition and matrix adsorption[2,6,7]. Out of these nitrification and de-nitrification processes are the main pathways for nitrogen removal[8,9]. However, wetland plants are an important component in a CW system and it also plays an important role in nitrogen removal. Further, type of plant species, type of wetland media, hydraulic regime such as flow direction, hydraulic loading rate (HLR), hydraulic retention time (HRT) etc. affect the nitrogen transformation rates in a wetland system. According to Shelef et al.[10] and Zhu et al.[11], mixed vegetation is more effective than single vegetation for pollutant removal in CWs. Thus the objective of this study was to evaluate the effects of mixed vegetation of two selected wetland plant species, for removal of nitrogen from wastewater using batch flow CW systems in tropics.

METHODOLOGY

This study was carried out by preparing twelve laboratory scale subsurface flow CW units of size 0.5 m x 0.66 m (Diameter x Height), using 10 – 20 mm gravel as the wetland media. They were kept at out-door, sheltered with a transparent roof in order to minimize the effects of rainfall, at Faculty of Engineering, University of Peradeniya. Sri Lanka($80^0 35^' 59^{''}$ E, $7^0 16^' 00^{''}$ N). The wetland units were planted with two locally available plant species; narrow-leaf cattail *(Typhaangustifolia)* and umbrella palms *(Cyperusalternifolius)* in three arrangements, viz., monoculture vegetation with cattails, monoculture vegetation with umbrella palm and mixed vegetation with cattails and umbrella palm. Each of these arrangements had four replicates and each wetland unit contained two plants. A schematic diagram of the prepared wetland units is shown in the **Fig. 1**.

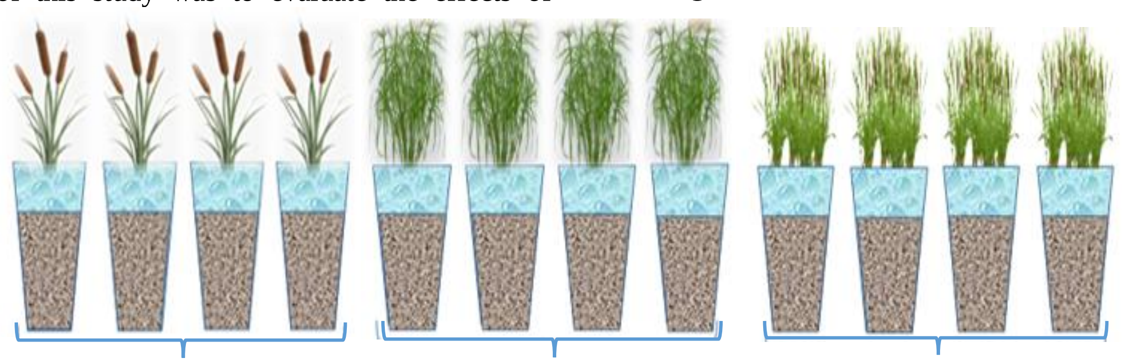

Fig. 1 : Schematic diagram of the wetland system

All the wetland units were fed with N rich synthetic wastewater at seven-days intervals as batch flow. Synthetic wastewater was prepared using: 30g of Urea, 75g of normal granular sugar, 10g of ammonium sulphate [$(NH_4)_2SO_4$], 10g of magnesium sulphate [$MgSO_4$], 0.25g of ferric chloride [$FeCl_3$], 1g of manganese sulphate monohydrate [$MnSO_4.H_2O$], 0.75g of calcium chloride monohydrate [$CaCl_2.H_2O$] and 250 mL of phosphate buffer solution, dissolved in 500L of tap water[4]. The composition of phosphate buffer solution had 8.5g of potassium dihydrogen phosphate [KH_2PO_4], 21.75g of potassium hydrogen phosphate [K_2HPO_4], 33.4g of sodium monohydrogen phosphate heptahydrate [$Na_2HPO_4.7H_2O$] and 1.7g of sodium chloride [NH_4Cl]in 1L of tap water[12]. Samples were collected from the influent and effluents of each wetland unit at seven-days interval and pH, EC, DO, T^0C, COD, NH_3-N, NO_3^--N and TN were measured. Then percentage removal efficiencies (RE) of each wetland arrangement were estimated according to the Equation 1. Further, plant growth measurements such as shoot height and shoot density were also monitored at seven-days interval. In addition, the plant nitrogen uptake and media adsorption were estimated at four-weeks interval. Finally, the nitrogen mass balance was analyzed in order to assess the major nitrogen removal pathways for each arrangement, according to the Equation 2.

$$RE = \left(\frac{(C_i - C_o)}{C_i}\right) * 100 \qquad (1)$$

$$TN_i = TN_o + TN_{Plantuptake} + TN_{Mediaadsorption} + TN_{Losses} \qquad (2)$$

Where, C_i = Influent concentration of the wastewaterparameter, C_o= Effluent concentration of the wastewaterparameter, TN_i= Influent total nitrogen concentration and TN_o= Effluent total nitrogen concentration.

RESULTS AND DISCUSSION

Wastewater characteristics

Average wastewater characteristics at the influent and effluents of all wetland units are shown in the **Table 1**. Accordingly, it was noted that the pH and temperature have slightly reduced from the influent to the effluents though the statistical analysis conducted using 'MINITAB 16' confirmed that there is no significant difference between influent and effluents of each wetland system. On the other hand, EC in the umbrella palm wetland units had been reduced from influent to the effluent, though the EC value of cattail and mixed vegetation wetland units had been increased than the influent. The decrease of EC could be a result of uptake of micro and macro elements and ions by plants and bacteria, and their removal through adsorption to plant roots, litter and settleable suspended particles[13]. Further it was noted that DO concentration has significantly reduced from influent to the effluents of all wetland units and could be due to the consumption of oxygen for bio-degradation of organic matter and nitrification of NH_3-N to NO_2^--N and NO_3^--N. Also, all three wetland units had removed TN, NO_3^--N and COD considerably, though NH_3-N removal had happened only in the umbrella plant wetland unit.

Table 1: Wastewater characteristics at the influent and effluent of each wetland arrangement (Average ± Standard deviation)

Parameter	Influent	Effluents		
		Cattail	Umbrella palm	Mixed vegetation
pH	7.58 ± 0.12	6.67 ± 0.09	6.48 ± 0.25	6.67 ± 0.1
EC (µS /cm)	197.1 ± 26.3	215.9 ±26.9	170.1 ± 35.5	222.4 ± 20.6
DO (mg/l)	6.91 ± 0.59	2.19 ± 0.91	2.8 ± 0.93	2.51 ± 0.82
Temperature (^{0}C)	26.3 ± 1.02	25.4 ± 1.03	25.1 ± 1.76	25.1 ± 1.45
TN (mg/l)	40.23 ± 2.302	11.52 ± 4.492	3.86 ±2.753	8.57 ± 3.55
NO_3^--N (mg/l)	1.54 ± 0.47	0.66 ± 0.66	0.59 ± 0.59	0.56 ± 0.56
NH_3-N (mg/l)	4.35 ± 1.16	7.83 ± 1.88	1.81 ± 1.68	6.19 ± 1.85
COD (mg/l)	170.1 ± 18.05	16.27 ±13.56	8.03 ±6.22	15.6 ±10.7

Removal efficiencies

Ammonia nitrogen (NH_3-N) removal

Fig. 2(a) presents the variation of NH_3-N removal efficiencies (REs) during the study period while **Fig. 3(a)** shows the average NH_3-N REs over the study period in all three wetland systems. Accordingly, umbrella palm wetland unit showed a considerable removal of NH_3-N over the study period with an average RE of 58.21%. However, cattail and mixed vegetation units showed an accumulation of NH_3-N within the system. The NH_3-N removal in a wetland system depend upon the rate of nitrification and rate of ammonification. For effective nitrification there should be sufficient oxygen, and in umbrella palm wetland systems the oxygen release rate through roots could have been positively affected for this higher NH_3-N removal than other two wetland units. The statistical analysis conducted using 'MINITAB

16' software showed that there is a significant treatment difference of NH_3-N removal between umbrella palm wetland system and both cattail and mixed vegetation wetland systems ($p < 0.05$). But there is no significant treatment difference between cattail and mixed vegetation wetland systems ($p > 0.05$).

Nitrate nitrogen (NO_3^--N) removal

Fig. 2 (b) presents the variation of NO_3^--N REs during the study period and all three wetland systems showed a similar variation pattern. **Fig. 3(b)** presents the average NO_3^--N REs over the study period in all three wetland systems. Accordingly, mixed vegetation wetland unit had a slightly higher removal of NO_3^--N (60.38%) than individually planted cattail (54.59%) and umbrella palm (58.48%) wetland units. The statistical analysis conducted by using 'MINITAB 16' statistical software had confirmed that there are no significant treatment difference between all three wetland systems ($p > 0.05$) for NO_3^--N removal. The major NO_3^--N removal mechanism in a wetland system is through the denitrification process, for which a sufficient carbon source and an anaerobic/anoxic environment should exist. Also the optimum pH range for effective denitrification is between 7-8.5[14] and the pH value in our wastewater in this study was around 7 and it might have positively affected. Kyambadde[15] has reported that in general the nitrification rate is slower than the denitrification rate, and thus it affects the latter.

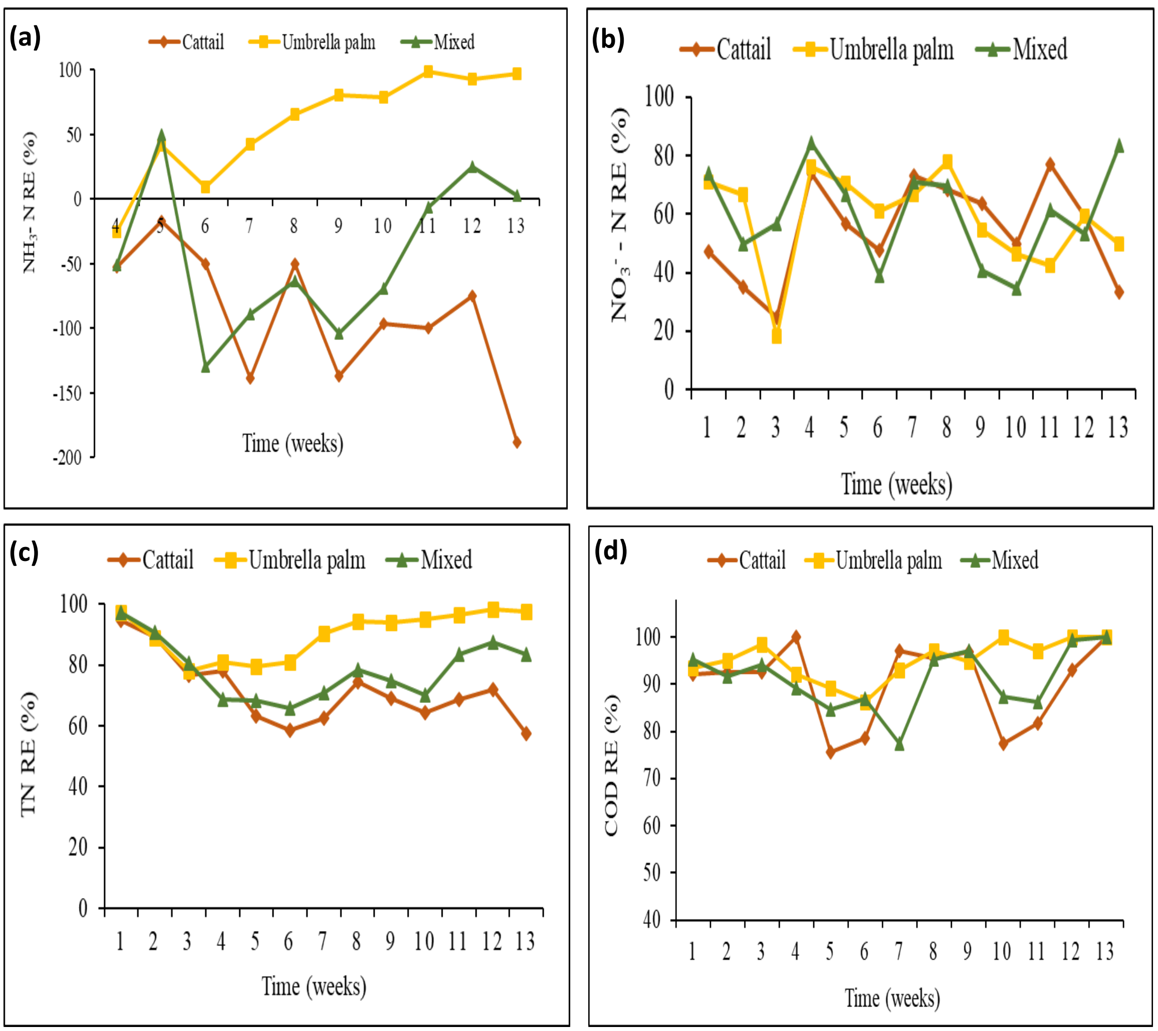

Fig. 2 : Variation of (a) NH_3-N, (b) NO_3^--N, (c) TN and (d) COD in cattail, umbrella palm and mixed vegetation wetland units during the study period

Total nitrogen (TN) removal

Fig. 2(c) presents the variation of TN REs during the study period and **Fig. 3(c)** shows the TN REs over the study period. Accordingly, the umbrella palm wetland unit had the highest TN RE of 75.06%, while cattail and mixed vegetation wetlands had 61.49% and 65.49% REs respectively. Statistical analysis showed there are significant difference of TN removal between umbrella palm wetland and other two wetland units ($p < 0.05$), revealing umbrella palm wetland units are better in TN removal. These results are also in agreement with Zhang et al.[16].

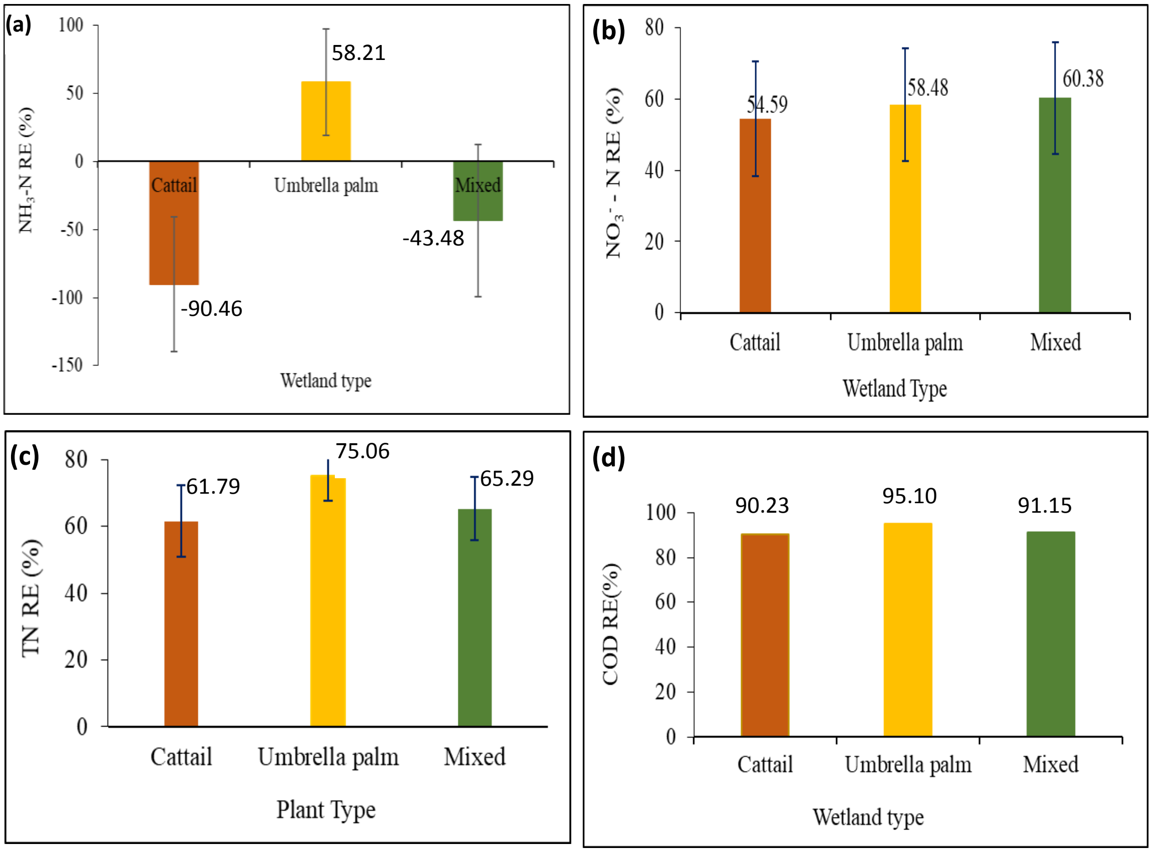

Fig. 3 : The average removal efficiencies of (a) NH_3-N, (b) NO_3^--N, (c) TN and (d) COD, in cattail, umbrella palm and mixed vegetation wetland units over the study period

Chemical oxygen demand (COD) removal

The variation of COD REs during the study period is presented in the **Fig. 2(d)** and the average COD REs over the study period is presented in the **Fig. 3(d)** for all three wetland units. Form **Fig. 2(d)** it was noted that COD REs have been varying over the time during the study period but average REs are almost same for all three wetland systems **(Fig.3 (d))**. The statistical analysis also showed there are no significant treatment difference of COD removal between three wetland systems ($p > 0.05$). This indicates that the mixing of cattail and umbrella palm has no effect in COD removal. In general COD removal in a wetland system is attributed to microbial degradation and for efficient COD removal there should be sufficient dissolved oxygen. However, the best COD removal was being achieved in the umbrella palm wetland unit.

Plant total nitrogen uptake and media adsorption

Table 2 presents the plant total nitrogen uptake results with respect to stems, leaves and roots in all three wetland units at 4-weeks interval. **Table 3** presents the media adsorption results obtained during the study period at each 4 weeks. Accordingly, it was noted that The highest plant uptake has been taken place in the mixed vegetation wetland unit. The statistical analysis showed a significant difference of nitrogen uptake ($p < 0.05$) between wetland systems. This could be due to the competition of growth among two plant species. On the other hand, from the **Table 3** it was noted that the cattail wetland unit had the highest media adsorption compared to other two. This could be due to the less root biomass in that system.

Table 2 : Plant total nitrogen uptake at four-week interval

Wetland Type		Plant uptake (mg/4 weeks)			
		1 – 4 weeks	4 – 8 weeks	8 – 12 weeks	Total
Cattail	Stems	31.4	94.45	13.77	139.62
	Leaves	38.15	53.72	25.83	117.7
	Roots	100.9	8.73	25.62	135.25
	Total	170.45	156.9	65.22	392.57
Umbrella Palms	Stems	39.46	68.25	37.09	144.8
	Leaves	30.4	119.9	33.8	184.1
	Roots	21.3	126.38	70.31	217.99
	Total	91.16	314.53	141.2	546.89
Mixed Vegetation	Stems	51.04	93.16	72	216.2
	Leaves	44.8	161.36	56.72	262.88
	Roots	62.23	142.87	59.57	264.67
	Total	158.07	397.39	188.29	743.75

Table 3 : Media adsorption at four-week interval

Wetland Type	Media adsorption (mg/4 weeks)		
	1 – 4 weeks	4 – 8 weeks	8 – 12 weeks
Cattail	183.61	383.07	488.16
Umbrella palms	215.4	364.02	447.58
Mixed vegetation	233.64	336.99	307.36

Nitrogen mass balance analysis

Fig. 4 presents the results of nitrogen mass balance analysis conducted using the Equation 2, for 1-4 week duration. Accordingly, it was clearly noted that the total nitrogen losses are higher in all three wetland systems than the plant uptake and media adsorption (Similar plots were obtained during 4-8 weeks and 8-12 week period). Nitrogen removal in a wetland system happens through various complex processes such as nitrification, denitrification, volatilization, plant uptake, media adsorption etc. Many researchers have reported that out of these processes nitrification and denitrification are the main nitrogen removal pathway and the results of this study too agrees with it.

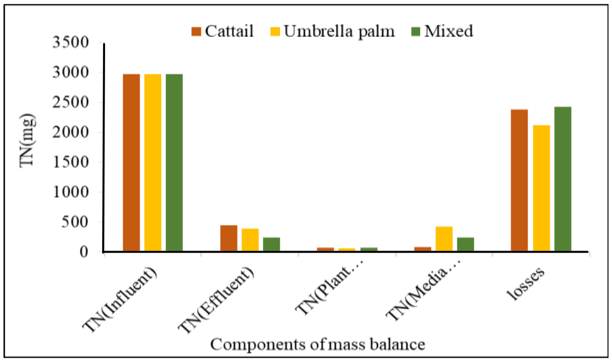

Fig. 4 : Results of nitrogen mass balance analysis for 1-4 weeks period

CONCLUSION

Results of the present study revealed that subsurface flow batch flow wetland units planted with umbrella palm show the best performance in nitrogen removal. Further, mixed vegetation wetland units planted with umbrella palm and cattail had no significant positive effect in nitrogen removal.

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