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A Study of Nutrient Removal Efficiency from Simulated Agriculture Run-off (SAR) Using Constructed Wetland Technology

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ABSTRACT

In this study, a vertical flow constructed wetland in batch mode was examined for the removal efficiency of simulated agricultural run-off (SAR) using gravel and soil as substrates, planted with *Canna*, *Typha* and *Eichhornia* plant species in single and mixed culture conditions. From this study, it was found that the constructed wetland (CW) planted with *Canna* + *Eichhornia* plant species (mixed) showed maximum removal efficiency of the studied parameters, i.e. phosphates, nitrates and ammonical nitrogen to the tune of 99%, 96% and 98%, respectively of simulated agricultural run-off as compared to other studied CWs. *Canna* and *Typha* macrophytes showed higher biomass and chlorophyll content, indicating better tolerance in the mixed culture CW system. Treatment efficiency improved when longer hydraulic retention times (HRTs) were used. Maximum treatment efficiency was shown by hybrid CW, which included the properties of the horizontal flow (HF) and vertical flow (VF) type CWs.

INTRODUCTION

In India, the problem of freshwater pollution is raising increasing day by day with domestic sewage and industrial waste discharges being the most critical sources of pollution. Major sources of water pollution include point and non-point sources like discharges from industries and stormwater respectively. Pollution from non-point sources such as agriculture run-off, leaching from waste disposal sites and stormwater is difficult to control, while pollution from point sources can be controlled by different treatment technologies. According to the Ministry of Environment and Forest (2009), the agricultural sector has a predominant impact on water quality. Overuse of chemical pesticides and fertilizers, by farmers due to heavy subsidies, increased per hectare consumption of fertilizers. The higher amount of nutrients applied to crops implies environmental pollution both from runoff (liquid phase) as well as sediment (solid phase) (Zuazo et al. 2004, Divya & Belagali 2012). Removal of nutrients through sediments and runoff water not only declines soil fertility but also causes environmental problems when these nutrients are transported further down the valleys, lakes, and reservoirs (Kin-Che et al. 1997). In India due to low literacy rate among farmers, makes them non-effective to understand the written instructions on pesticide containers which results in an improper application, over application and lack of training are a couple of examples of different ways of reaching pesticides and fertilizers in rivers and water bodies (Abhilash & Singh 2009). Nonpoint-source pesticide pollution from agricultural areas is widely regarded as one of the greatest causes of contamination of surface waters (Gangbazo et al. 1999, Humenik et al. 1987, Line et al. 1997). Mandal et al. (2012) also studied Runoff, sediment, and nutrient losses from an agricultural field under natural rainfall events in a semi-arid tropical region of India, which contributes to increasing non-point source pollution and the risk of eutrophication in lowland surface water bodies. The average nutrient losses during 2005-2009 were 41.72 kg ha^{-1} yr^{-1} for total C, 10.2 kg ha^{-1} yr^{-1} for total N, 1.0 kg ha^{-1} yr^{-1} for total P, and 20.07 kg ha^{-1} yr^{-1} for total K. loss of soil 560-1010 kg ha^{-1} yr^{-1} with 3.9 kg N, 2.1-2.4 kg P and 1.6-10.2 kg K from agricultural soil in a semi-arid region of India was also reported by Mishra et al. (2010). Nitrogenous fertilizers are the main source of NO_3^- pollution in groundwater and other water bodies (Schepers et al. 1984). A high concentration of nitrate, ranging from 2.8 to

91 mg.L^{-1} in water samples collected from hand pumps in the industrial areas of Ludhiana town was also reported by Goyal et al. (1981). Groundwater samples from Haryana and Punjab where fertilizer consumption is highest showed high amounts of nitrate in the groundwater (Lunkad 1994). Several studies also reported higher concentrations of nitrate concentrations in groundwater samples of different districts (Lakshmanam et al. 1986, Singh et al. 1991, Tamta et al. 1992, Handa 1986, Kumar & Singh, 1988). So for the treatment of such type of wastewater advanced technology was needed which is more environment-friendly, low in cost, and maintenance. In the early 1970s constructed wetlands (CWs) were mainly used for the treatment of domestic or municipal sewage (Vymazal et al. 2006). After the 1990s application was expanded to treat different kinds of wastewater including agricultural wastewaters (Zhou et al. 2004), dairy wastewater (Kern & Brettar 2002), and landfill leachate (Bulc 2006). Most of the initial studies referred to the potential of wetlands for the removal of herbicides and some other organic chemicals (Kadlec & Hey 1994, More et al. 2000). Treatment of wastewater in constructed wetland systems includes various biological and biochemical processes. Thus, constructed wetland technology has been found useful in treating wastewaters of various types in an environmentally friendly manner. The present study is proposed to examine the efficiency of different types of constructed wetland systems to treat various organic and inorganic chemicals present in the agricultural run-off, which is very important in the agriculturally predominant state of Haryana.

MATERIALS AND METHODS

Experimental Setup and Design

Batch mode: Normal washing buckets with a capacity of 15 L and a working volume of 3 L were used in the experiment as CW reactors. The buckets were fitted with rubber tubing, a few centimeters (2”) from the bottom, and screw clips were used to close the rubber tubing. Soil and gravel were used as the substrate. The gravels were thoroughly washed with tap water and placed at the bottom of the bucket followed by soil and then gravel again. Macrophytes *Canna, Typha,* and *Eichhornia* in single and mixed cultures were used as the wetland plants. Various combinations of the plant species used in variously constructed wetland reactors were C=CW_1, T=CW_2, E=CW_3, C+T=CW_4, C+E=CW_5, E+T=CW_6 and E+C+T=CW_7 where C represents *Canna*, T: *Typha* and E for *Eichhornia*. CW represents the constructed wetland systems and numbering is given to various reactors with different macrophyte combinations. The experimental plants were cleaned with distilled water and then these plants were acclimatized in reactors containing fresh tap water for 5-7 days under natural environmental conditions. Simulated wastewater was loaded at the surface of the wetland system and collected at fixed time intervals through an outlet of the reactor. Sampling was done every 24 h and the sample was analyzed for various parameters.

Continuous mode: CW reactors made of Stainless Steel (60x30x30 cm) were fabricated for use as Horizontal, Vertical and Hybrid subsurface flow Constructed Wetland systems. For Horizontal flow CWs layer of gravel at the inlet and outlet of the reactor was placed, portioning was done with the help of plates of stainless steel, and the middle part of the reactor was filled with soil for planting the macrophytes. In vertical flow CWs, a layer of gravel at the bottom was followed by a layer of soil, and then again gravel layer was placed. The wastewater was fed into the reactor at a required HRT with the help of a peristaltic pump through the inlet. Both soil and gravel were used as substrates in the reactors which had a working volume of 10 L.

Preparation of Simulated Agricultural Run-off (SAR)

Simulated agricultural runoff was prepared by dissolving Urea, and DAP (Diammonium phosphate) in tap water. The simulated agricultural runoff was characterized for various parameters like pH, orthophosphates, nitrate, and ammonical nitrogen using standard methods (APHA 1995).

Analytical Methods

Simulated agricultural runoff was analyzed for various parameters such as pH, electrical conductivity (EC), using a pH-EC meter, nitrate-nitrogen (NO_3^--N) by colorimetric method using brucine sulphanilic acid, total nitrogen (TN), ammonical nitrogen (NH_4^+-N) by colorimetric method using Nessler’s reagent, phosphate (PO_4^{3-}) by molybdenum-blue complex method (APHA 1995). Chlorophyll (a, b and Total) was measured by using Arnon’s (1949) method.

RESULTS AND DISCUSSION

Initial Characteristics of Simulated Agricultural Run-off were Analyzed and given in Table 1.

Table 1: Characteristics of simulated agricultural run-off used in the batch experiment.

Parameter	Parameter value
pH	8.03
Phosphate [mg.L^{-1}]	52.6
Nitrate [mg.L^{-1}]	1.9
Ammonical Nitrogen [mg.L^{-1}]	34.15

Change in pH of Batch Treated SAR

During the experiment pH of simulated agricultural runoff changed from alkaline to neutral in all studied Constructed Wetland systems (CWs). A gradual trend of decrease in pH was observed during the 16 days of the experiment (Fig. 1).

Removal of Nitrates From Batch-Treated SAR

In the initial 4 days of the experiment, there was a sharp increase in the concentration of nitrate which could be due to the conversion of ammonical nitrogen into nitrate by nitrifying bacteria present in the CW substrate and root zone of the plants.

After 4 days, the concentration of nitrates started declining (Fig. 2) which may be due to the removal mechanisms; denitrification, storage in the substrate, uptake, and storage in plant biomass in constructed wetland systems (Brix 1993).

Most of the differences in nitrate concentrations in treated run-off from CWs with different types and combinations of plants exceeded the critical difference value (CD = 0.6) showing a significant effect due to plant type present in the CW microcosms (Table 2).

Change in Ammonical Nitrogen (NH_4^+-N) Concentration of Batch Treated SAR

Concentration of ammonical nitrogen was reduced (Fig. 3) to 1.67 mg.L^{-1}, 4.77 mg.L^{-1}, 6.24 mg.L^{-1}, 0.74 mg.L^{-1}, 2.64 mg.L^{-1}, 3.06 mg.L^{-1} and 2.84 mg.L^{-1} for CW_1, CW_2, CW_3, CW_4, CW_5, CW_6 and CW_7, respectively, from an initial value

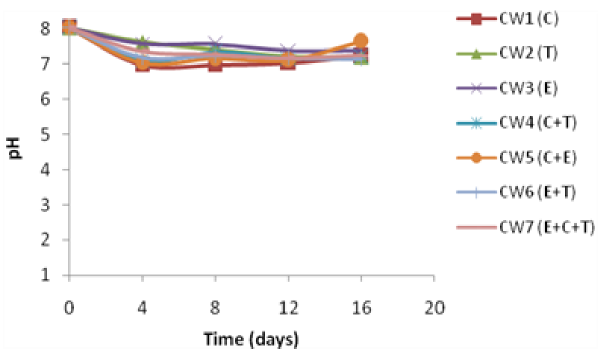

Fig. 1: Change in pH of treated SAR in CWs with different wetland macrophytes.

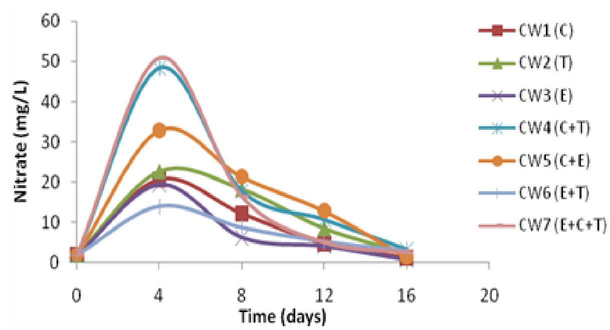

Fig. 2: Change in nitrate concentration of treated SAR in CWs with different wetland macrophytes.

Table 2: Statistical significance of differences in nitrate concentration after 16d batch treatment by C*anna*, T*ypha,* and *Eichhornia* in their different combinations in CW microcosms based on Critical Difference (CD= 0.6).

Canna	**C- T**	**C- E**	**C- CT**	**C- CE**	**C- TE**	**C- CTE**	**CT- CE**	**CT- CTE**
4	1.9	1.3	27.7	12.1	6.7	30.1	15.6	48.4
8	6	5.9	5.6	9.1	3.5	4.2	3.5	17.8
12	3.76	0.57*	6	8.1	0.53*	0.3*	2.1	10.7
16	1.16	0.41*	2.13	0.13*	1.73	1.33	2	3.3
Typha	**T-C**	**T- E**	**T- CT**	**T- CE**	**T- TE**	**T- CTE**	**TE- CT**	**TE- CTE**
4	1.9	3.2	29	15.6	18.8	36.8	34.4	14
8	6	11.9	0.4*	3.1	9.5	1.8	9.1	8.7
12	3.76	4.33	6.57	2.1	7.57	0.23*	5.47	5.23
16	1.16	1.57	2.54	2	1.6	0.4*	0.4*	2.9
Eichhornia	**E-C**	**E-T**	**E- CT**	**E- CE**	**E- TE**	**E- CTE**	**ET- CE**	**EC- CTE**
4	1	2.9	29	13.4	5.4	31.4	18.8	32.8
8	5.9	11.9	11.5	15	2.4	10.1	12.6	21.3
12	0.57*	4.33	6.57	8.67	1.1	0.87	7.57	12.8
16	0.41*	1.57	2.54	0.54*	2.14	1.74	1.6	1.3

**Non-significant ($p>0.05$)*

of 34.15 mg.L^{-1}. The highest treatment efficiency (91.8%) was recorded for CW_5 planted with *Canna* and *Eichhornia* plant species in mixed combinations after 16 days of treatment (Table 4). A sharp fall in NH_4^+-N concentrations in the treated SAR from the beginning suggests the transformation of this form of nitrogen to nitrate, which showed an increase in the beginning.

Most of the comparisons show differences greater than CD, indicating the effects of these different plant combinations to be statistically significant as shown in Table 3.

Removal of Phosphates from Batch-Treated SAR

In all the studied CW systems, there was a sharp decrease in the concentration of phosphate right from the beginning of the experiment followed by stabilization with time (Fig. 4). Phosphate concentration reduced from initial 52.64 mg.L^{-1} to 0.53, 0.73, 0.68, 1.13, 0.21, 1.2 and 0.57 mg.L^{-1} for CW_1, CW_2, CW_3, CW_4, CW_5, CW_6 and CW_7, respectively showing very rapid and high removal. No significant difference in the removal of phosphate was observed between pairs of constructed wetland microcosms.

Percentage removal efficiency for all the CWs was in the range of 97% to 99% with a maximum in CW_5 as shown in Table 4. Inorganic phosphate in dissolved form can form complexes with ligands and these complexes get bound to the soil/media structure through adsorption and precipitation process. While under aerobic conditions, phosphate forms insoluble complexes with hydrous oxides of aluminum, iron, and calcium (Sakadevan & Bavor 1998).

Based on the above results, it may be concluded that all the CWs planted with single or mixed cultures of wetland macrophytes were quite efficient in the removal of different

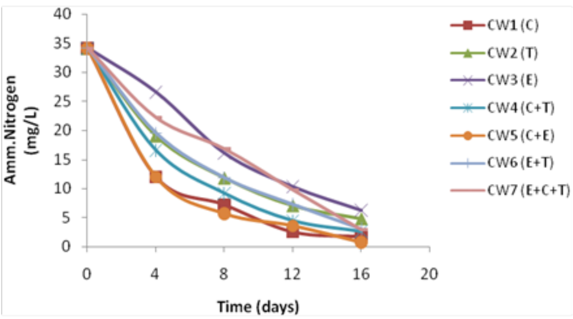

Fig. 3: Change in ammonical nitrogen concentration of treated SAR in CWs with different wetland macrophytes.

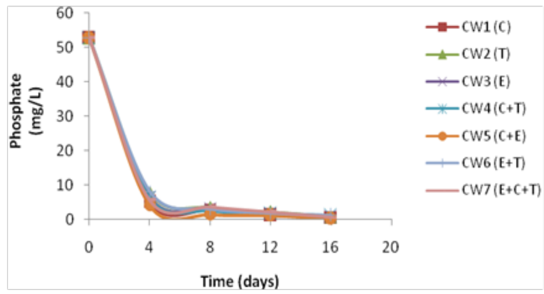

Fig. 4: Change in phosphate concentration of treated SAR in CWs with different wetland macrophytes.

Table 3: Statistical significance of differences in ammonical nitrogen concentration after 16d batch treatment by *Canna*, *Typha* and E*ichhornia* in their different combinations in CW microcosms based on Critical Difference (CD = 0.6).

Canna	**C- T**	**C- E**	**C- CT**	**C- CE**	**C- TE**	**C- CTE**	**CT- CE**	**CT- CTE**
4	7.08	14.6	4.62	0.04*	7.58	10.2	4.58	5.58
8	4.63	8.91	2.03	1.49	4.6	9.59	3.52	7.56
12	4.53	7.81	2.01	1.1	4.79	7.22	0.91	5.21
16	3.1	4.57	0.97	0.93	1.39	1.17	1.9	0.2*
Typha	**T-C**	**T- E**	**T- CT**	**T- CE**	**T- TE**	**T- CTE**	**TE- CT**	**TE- CTE**
4	7.08	7.52	2.46	7.04	0.5*	3.12	2.96	2.62
8	4.63	4.28	2.6	6.12	0.03*	4.96	2.57	4.99
12	4.53	3.28	2.52	3.43	0.26*	2.69	2.78	2.43
16	3.1	1.47	2.13	4.03	1.71	1.93	0.42*	0.22*
Eichhornia	**E-C**	**E-T**	**E- CT**	**E- CE**	**E- TE**	**E- CTE**	**ET- CE**	**EC- CTE**
4	14.6	7.52	9.98	14.56	7.02	4.4	7.54	10.16
8	8.91	4.28	6.88	10.4	4.31	0.68	6.09	11.08
12	7.81	3.28	5.8	6.71	3.02	0.6	3.69	6.12
16	4.57	1.47	3.6	5.5	3.18	3.4	2.32	2.1

**Non -significant (p>0.05)*

Table 4: Nutrient removal efficiency of Constructed Wetland Microcosms (CWMs) with different wetland macrophytes in 16 days' batch treatment.

Parameter	Removal Efficiency (%)						
	CW_1 (C)	CW_2 (T)	CW_3 (E)	CW_4 (C+T)	CW_5 (C+E)	CW_6 (E+T)	CW_7 (E+C+T)
Phosphate	99	99	99	98	99	98	99
Nitrate	94	90	96	93	96	79	95
Ammonical Nitrogen	95	86	82	92	98	91	92

nutrients within 16d of the treatment period. But CW_5 planted with *Canna* + *Eichhornia* plant species showed maximum removal efficiency as compared to other studied CWs.

A perusal of Table 4 clearly shows very high efficiency (79-99 %) of the CWMs in treating the run-off (SAR) with maximum efficiency being in the case of CW_5 (C+E), which showed 96-98 % removal of the major nutrients (PO_4^{3-}, NO_3^- and NH_4^+).

Growth and Tolerance of the Wetland Macrophytes in CWs Treating Simulated Agricultural Run-off (SAR)

The capacity of the wetland macrophytes to tolerate and grow in the high concentration of nutrients and agrochemicals is important since that is going to decide the overall performance of the planted CWs. Therefore, biomass and chlorophyll content of leaves (Chl a, b and total) of the macrophytes and biomass from all the CWs were determined at the initial (0d) and the termination of the experiment (16d), taking biomass and chlorophyll content as an important index of growth and tolerance, changes in these parameters are shown in Fig. 5.

An increase in the chlorophyll content and relative biomass was observed in single and mono culture *Canna* and *Eichhornia* macrophytes. *Typha* plant in monoculture shows a decline in the relative biomass and chlorophyll content, while in combination with *Eichhornia* macrophyte slight increase in the chlorophyll content and biomass was observed as given in Table 5.

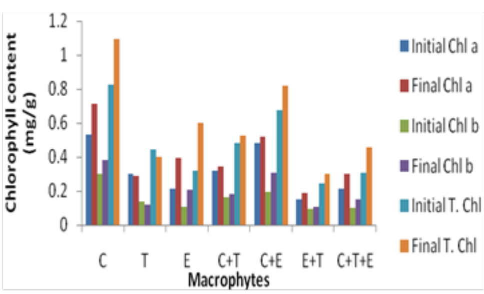

Fig. 5: Change in leaf chlorophyll content of the wetland plants in CWMs treating agricultural run-off.

Treatment of Simulated Agricultural Runoff (SAR) in Constructed Wetland in Continuous mode at Different Flow Rates

In this experiment different types of Constructed Wetland systems (CWs) viz. Horizontal flow, Vertical flow and hybrid CW were used with different HRTs (2, 4 & 6 days) at corresponding flow rates of 3.4, 1.7 & 1.1 ml/min., to compare the treatment efficiency of simulated agricultural runoff (SAR). *Canna (C) and Eichhornia (E)* (observed best combination plant species from the plant optimization experiment for treatment of SAR in batch mode) in mixed culture conditions were used as the wetland plants, with soil + gravel as a substrate for treatment of the SAR. Characteristics of the SAR are shown in Table 6.

During the experiment pH of the simulated agricultural run-off remained alkaline in all studied constructed wetland systems (CWs), showing minor variations.

Removal of Phosphate from SAR in HF, VF and Hybrid CW

Variations in phosphate concentration of the SAR at different HRTs in the Horizontal flow, Vertical flow and Hybrid CW systems are depicted in Fig. 6. At 2d HRT, there was a decline in phosphate concentration from an initial 35.5 mg/L to 18 mg/L, 12.8 mg/L, 11.6 mg/L, 6.4 mg/L, 4.5 mg/L and 3.2 mg/L in the unplanted HF, planted HF, unplanted VF, planted

Table 5: Relative change in biomass of the plants in the CW treating SAR.

Macrophyte	C	T	E	CT	CE	ET	ECT
Relative Biomass (g)	142	88	114	147	161	110	138

*Initial plant weight was taken as 100.

Table 6: Characteristics of SAR.

Parameter	Parameter value
pH	7.64
Phosphate ($mg.L^{-1}$)	35.5
Amm. Nitrogen ($mg.L^{-1}$)	18.3
Total Nitrogen ($mg.L^{-1}$)	15.5

VF, unplanted Hybrid and planted Hybrid CWs, respectively. At 4d HRT, phosphate concentration decreased from 35.5 mg/L to 14.6, 8.26, 7.28, 3.2, 2.1 and 1.4 mg/L in the unplanted HF, planted HF, unplanted VF, planted VF, unplanted Hybrid and planted Hybrid CWs, respectively. At 6d HRT, the concentration of phosphate declined from an initial 35.5 mg/L to 8.03, 5.5, 2.3, 1.9 and 0.4 mg/L in the unplanted HF, planted HF, unplanted VF, planted VF, unplanted Hybrid and planted Hybrid CWs, respectively shown in Fig. 6.

Maximum removal of phosphate (99%) was observed at 6d HRT, in Hybrid CWs followed by 96% and 91% at 4 and 2 days HRT, respectively (Table 7).

Whereas VF CW showed better phosphate removal compared to HF CW for both planted and unplanted reactors. This indicates the good nutrient removal capacity of VF compared to HF. The phosphate removal efficiency of all types of CWs improved when longer HRT was used which

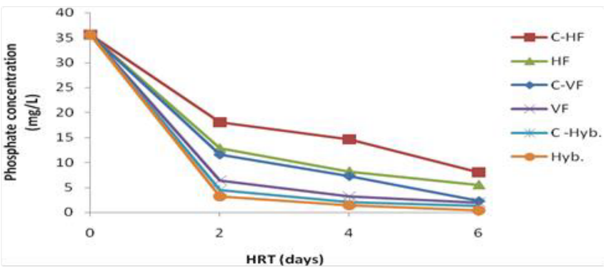

Fig. 6: Change in phosphate concentration of treated SAR in HF, VF and hybrid CWs at different HRTs.

Table 7: Percentage removal of nutrients and pesticides from SAR in HF, VF and Hybrid CWs at different HRTs.

Parameter	HRT (d)	Removal Efficiency (%)					
		C-HF	HF	C-VF	VF	C-Hybrid	Hybrid
Phosphate	2	49	64	67	82	87	91
	4	59	77	80	91	94	96
	6	77	84	93	94	96	99
Ammonical Nitrogen	2	22	27	26	33	40	49
	4	29	43	43	65	55	62
	6	51	62	61	72	74	80
Total Nitrogen	2	10	14	15	17	39	43
	4	28	38	42	55	61	70
	6	51	61	65	70	80	89

HF= Horizontal flow, VF= Vertical flow, Hybrid= Hybrid Constructed Wetland Systems, C= unplanted control

suggests that greater contact times facilitate nutrient removal by CWs (Akratos & Tsihrintzis, 2007).

Removal of Ammonical Nitrogen

Variations in ammonical nitrogen concentration of the SAR at different HRTs in the Horizontal flow, Vertical flow and Hybrid CW systems are depicted in Fig. 7. At 2d HRT, there was a decline in ammonical nitrogen concentration from an initial 18.3 mg/L to 14.26 mg/L, 13.3 mg/L, 13.5 mg/L, 12.3 mg/L, 11 mg/L and 9.4 mg/L in the unplanted HF, planted HF, unplanted VF, planted VF, unplanted Hybrid and planted Hybrid CWs, respectively.

At 4d HRT, ammonical nitrogen concentration decreased from 18.3 mg/L to 12.9, 10.5, 10.4, 6.4, 8.2 and 7 mg/L in the unplanted HF, planted HF, unplanted VF, planted VF, unplanted Hybrid and planted Hybrid CWs, respectively. At 6d HRT, the concentration of ammonical nitrogen declined from an initial 18.3 mg/L to 9, 6.9, 7.2, 5.16, 4.7 and 3.6 mg/L in the unplanted HF, planted HF, unplanted VF, planted VF, unplanted Hybrid and planted Hybrid CWs, respectively. In this case, also hybrid systems performed best compared to VF and HF. Since, greater removal of ammonical nitrogen indicates the establishment of aerobic conditions in the reactors, it can be deduced that HF CWs probably did not have a sufficient aerobic environment that could facilitate nitrification and hence they showed the least ammonical nitrogen removal. Moreover, it was observed that all the planted reactors showed better removal efficiency than the unplanted ones in their respective flow types. This might be due to the root zone effect which somehow enhanced the nitrification process by the release of oxygen in the rhizosphere (Fan et al. 2012).

Removal of Total Nitrogen from SAR in HF, VF and Hybrid CW

Change in total nitrogen concentration of SAR at 2d HRT, from an initial 15.5 mg/L to 14 mg/L, 13.4 mg/L, 13.1 mg/L, 12.8 mg/L, 9.4 mg/L and 6.8 mg/L in the unplanted HF,

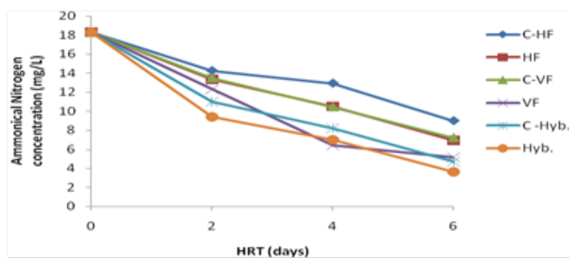

Fig. 7: Change in ammonical nitrogen concentration of treated SAR in HF, VF and hybrid CWs at different HRTs.

planted HF, unplanted VF, planted VF, unplanted Hybrid and planted Hybrid CWs, respectively. At 4d HRT, total nitrogen concentration decreased from 15.5 mg/L to 11.1, 9.6, 8.9, 7, 6.1 and 4.7 mg/L in the unplanted HF, planted HF, unplanted VF, planted VF, unplanted Hybrid and planted Hybrid CWs, respectively. At 6d HRT, concentration of total nitrogen declined from an initial 15.5 mg/L to 7.5, 6, 5.4, 4.6, 3.1 and 1.7 mg/L in the unplanted HF, planted HF, unplanted VF, planted VF, unplanted Hybrid and planted Hybrid CWs, respectively as shown in Fig. 8.

As it is evident from the results that the total nitrogen removal also followed a similar trend to that of removal of ammonical nitrogen. All CW systems showed an appreciable decrease in the concentration of total nitrogen after 6d HRT but planted hybrid CW showed maximum removal efficiency of 89% at 6d, HRT (Table 7). It is therefore considered that all the factors viz. high retention time, presence of vegetation, the microflora of rhizosphere and flow of wastewater in the hybrid system probably played a considerable part in maintaining adequate conditions for nitrification and denitrification which resulted in maximum removal of total nitrogen from wastewater. Arivoli and Mohanraj (2013) also reported that combined nitrification and denitrification along with sedimentation are specific processes for the treatment of nitrogen forms in a vertical flow CWs planted with *Typha angustifolia*.

Vertical flow CW was found to be more efficient than horizontal flow CW in removing various pollutants at different HRTs. Hybrid CW was most efficient for the removal of all pollutants, showing 91-99% removal of phosphate, 49-80% of ammonical nitrogen 43-89% of total nitrogen (Table 4.10). Removal in VF CWs was in the range of 17-94% and that in HF CWs varied from 14-84%. Planted CWMs showed greater removal than unplanted CWs in all (HF, VF and Hybrid CWs).

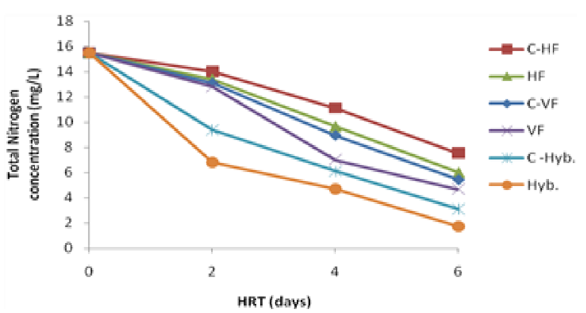

Fig. 8: Change in total nitrogen concentration of treated SAR in HF, VF and Hybrid CWs at different HRTs.

CONCLUSION

Based on the above results, it may be concluded that CWs planted with *Canna* + *Eichhornia* plant species in mixed cultures were very efficient in treating the nutrients present in agricultural run-off (SAR). *Canna indica* and *Typha latifolia* bi-culture showed 96-98% removal of the major nutrients (PO_4^{3-}, NO_3^- and NH_4^+) from simulated agricultural run-off (SAR) along with an increase in the leaf chlorophyll content and relative biomass Treatment efficiency improved when longer HRTs were used. Hybrid CW (which includes the properties of HF and VF types of CWs) had maximum removal of all nutrients, 91-99% removal of phosphate, 49-80% of ammonical nitrogen 43-89% of total nitrogen.

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