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SEMI-SURFACE HORIZONTAL FLOW CONSTRUCTED WETLAND TREATMENT OF DOMESTIC SEWAGE EFFLUENT: EFFECT ON SOIL PROPERTIES

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ABSTRACT

A field experiment was conducted at the Main Agricultural Research Station, Dharwad, Karnataka, India during January to May, 2014 to study the effect of irrigation with domestic sewage effluent, treated through a semi-surface horizontal flow constructed wetland system on soil physico-chemical properties. The results showed significantly lower values in most of soil properties at all times of observation due to irrigation with treated sewage effluent over the untreated. The cumulative effect of irrigation treatments were better reflected at the harvest stage of crop. The ameliorative soil parameters *viz*; pH, electrical conductivity (dS m^{-1}) and exchangeable sodium percentage were low under treated sewage effluent irrigation (7.81, 0.18 and 8.27, respectively) over the untreated (8.07, 0.23 and 10.48, respectively). Similar trends were also observed in soil organic carbon, exchangeable cations, available boron and cation exchange capacity. Groundwater irrigation alone accounted for significantly lower values for all these parameters. Raw effluent irrigation along with 100 per cent recommended dose of fertilizers recorded higher values for organic carbon, exchangeable calcium, cation exchange capacity and exchangeable sodium percentage compared to other fertilizer combinations and irrigation sources. The study concluded that irrigation

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INTRODUCTION

The scarcity of fresh water resources necessitated the exploitation of new water sources to cope with all water demanding sectors. As for as agriculture is concerned, water is the major limiting resource not only in the traditional dry areas but also in the humid regions. Since Indian agriculture cannot depend on rainfall alone, sewage water and other wastewater resources are becoming increasingly important to be tapped.

Sewage irrigation is an age old agriculture practice and is being practiced in different parts of the world (Page *et al*., 1983; Pandey and Srivastava, 2009). Multiple benefits have been documented across soil types and climates around the globe owing to sewage irrigation. Irrigation with domestic wastewater resulted in build up of organic matter content of the soil (Rattan *et al*., 2005; Qishlaqi *et al*., 2008 ; Kiziloglu *et al*., 2008; Vogeler, 2009; Mojiri, 2011; Al Omron *et al*., 2011; Bhat, 2011; Mollahoseini, 2013), exchangeable cations and cation exchange capacity (Kiziloglu *et al*., 2008; Qishlaqui *et al*., 2008; Bhat, 2011) and available macro and micronutrients (Dash, 2010; Rana *et al*., 2010; Mojiri, 2011; Singh and Agarwal, 2012; Ladwani *et al*., 2012; Singh *et al*., 2012). The literature suggested both increase (Qishlaqi *et al*.,2008; Vogeler, 2009; Blum *et al*.,2012) and drop in pH (Rattan *et al*., 2005; Rana *et al*., 2010; Mojiri, 2011; Al Omron *et al*., 2011; Mollahoseini, 2013) due to sewage irrigation depending on the initial soil pH. These benefits, unfortunately and largely were accompanied by the adverse effects like increase in salt content (Kiziloglu *et al*., 2008; Mojiri, 2011; Anastasis *et al*., 2014). The hidden evils linked with raw sewage irrigations are accumulation of toxic heavy metals (Rana *et al*., 2010), biological contaminants and other toxic compounds in the environment (Pedrero and Alarcon, 2009).

The literature also suggested the distinct possibility of producing high yield with reduced use of N fertilizer which is also considered to help in minimizing the ground water contamination by nitrates (Raj *et al*., 2007). Farmers prefer to use sewage effluent as it contains essential nutrients and thus it reduces the costs on fertilizer inputs (Pandey and Srivastava, 2009). Irrigation with domestic sewage along with fertilizers showed an improvement in the nutrient status of the soil (Singh *et al*., 2012) and contributed for higher yields.

The farmers in India are generally using raw wastewater for vegetable production. The continuous and direct use of untreated wastewater for growing vegetable crops may create multifaceted problems like human and animal health hazard, groundwater pollution, reduction in crop yield and quality due to indiscriminate use. Treating wastewater prior to field application offers new vistas (Dash, 2010) in enhancing water availability for agricultural activities and provides a means for waste disposal (Hameed *et al.*, 2010). Irrigation with treated effluent will reduce the risk of contamination of soil and groundwater but making the best use of its nutrient reserves. Constructed wetlands are considered primly a cheaper and eco-friendly method (Dash, 2010) to treat wastewaters utilizing natural processes (Brix *et al.*, 2011).

Constructed wetland has been used to treat many types of wastewater at various levels of treatment around the globe. Natural soil-water-plant eco-systems are created in constructed wetlands to duplicate the physical, chemical and biological processes of natural wetland systems. Use of hydrophytes in constructed wetlands is reported to impart phytoremedial effects and help in reducing the pollutants and improving the quality of the wastewater (Patel and Kanungo, 2010). The present study was aimed at studying the effect of untreated and treated sewage irrigation on soil properties. The sewage effluent was treated through a semi-surface horizontal flow constructed wetland system.

MATERIALS AND METHODS

The study was carried out at the Main Agricultural Research Station, Dharwad, Karnataka, India during summer (January to May) 2014. The study was aimed at assessing the influence of fertilizer levels in combination with sources of irrigation water on physico-chemical properties of soil. The experiment was laid out in a split-plot design with four irrigation sources *viz*. groundwater, untreated sewage effluent (raw), treated sewage effluent and conjunctive mode (alternate irrigation with untreated sewage effluent and groundwater) as main plots and four fertilizer levels *viz*., 50 per cent recommended doses of N, P_2O_5 and K_2O + biofertilizers (F_1), 75 per cent recommended doses of N, P_2O_5 and K_2O + biofertilizers (F_2), 100 per cent of recommended doses of N, P_2O_5 and K_2O alone; no biofertilizers (F_3) and no fertilizers (F_4) as sub plots. The soil samples were collected at 30 and 60 days after transplanting and at harvest of test crop.

For treating the domestic sewage effluent, the domestic sewage of the University campus was converged at one point, allowed to undergo sedimentation in the inlet tank and passed though constructed wetland system. In the present study, the surface flow constructed wetland system (Vymazal, 2010) was slightly modified to have a semi-surface horizontal flow system using locally available bedding materials like brick pieces and charcoal to target higher treatment efficiency. The vegetated (*Brachiaria mutica*) channel (1.2 m width and 0.3 m depth) was horizontally and sequentially bedded with 2.0 m length strips each of big sized boulders (30-45 cm size), small sized boulders (25-30 cm size), jelly (~ 2.0 cm size), sand (0.025 cm size), broken bricks (5-10 cm size) and lastly charcoal (5-10 cm size). Each such filter strip along the grassy channel was separated by 1.0 m distance (Fig.1). The domestic sewage was allowed to flow through treatment channel from inlet and the treated wastewater was collected in outlet and used for irrigating the test crop (tomato). The flow rate was calculated as approximately 0.625 m^3 $hour^{-1}$ and the hydraulic retention time of around 2.5 days. The water samples were collected periodically at 7 days interval for assessing its mean quality.

The untreated sewage effluent, treated sewage effluent and groundwater samples were analyzed for irrigation quality parameters following standard procedures (Tandon 1998 ; ; APHA – AWWA - WPCF, 1980) and the mean values over the period was calculated. The collected soil samples were analyzed for pH, electrical conductivity, organic carbon, total carbon, available B, exchangeable cations (calcium and sodium), cation exchange capacity and exchangeable sodium percentage as per standard procedures (Sparks 1996 ; Tandon 1998).

RESULTS AND DISCUSSION

The important quality parameters of the sources of irrigation water (*i.e.*, untreated and treated sewage effluents and groundwater) are given in Table 1. The water quality parameters *viz*; pH, electrical conductivity, total solids, total suspended solids, total dissolved solids, biological oxygen demand, chemical oxygen demand, cations (calcium + magnesium and sodium), sodium adsorption ratio, residual sodium carbonate, boron and total carbon were relatively low in the treated sewage effluent compared to untreated sewage effluent; groundwater recording the lowest.

The effect of irrigation with different sources of water on soil pH and electrical conductivity at 30 and 60 days after transplanting and at harvest is presented in Table 2 and 3. The soil pH and electrical conductivity of the plots irrigated with untreated sewage effluent were significantly higher (8.10

Table 1: Mean physico-chemical composition of untreated (USE) and treated (TSE) sewage effluents in comparison with groundwater (GW)

Parameters	Overall mean		GW
	USE	TSE	
1. pH	7.33	6.88	6.91
2. EC (dS m^{-1})	0.83	0.76	0.72
3. Total solids (mg L^{-1})	1044	760	20
4. Total suspended solids (mg L^{-1})	480	278	8
5. Total dissolved solids (mg L^{-1})	662	446	12
6. BOD (mg L^{-1})	256	118	9
7. COD (mg L^{-1})	410	251	14
8. Ca+ Mg (me L^{-1})	7.27	6.09	1.06
9. Sodium (me L^{-1})	8.34	6.20	3.22
10. SAR ($mmol^{1/2}$ $L^{-1/2}$)	4.16	3.67	2.36
11. RSC (me L^{-1})	4.35	2.28	-2.70
12. Boron (mg L^{-1})	2.14	1.00	0.60
13. Total carbon (mg L^{-1})	286	162	41

Table 2: Effect of wastewater irrigation and fertilizer levels on soil pH

Fertilizer	30 DAT					60 DAT					At harvest				
levels(F)	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean
F1	7.92	7.95	8.06	7.93	7.96	8.03	7.92	8.21	8.17	8.09	7.94	7.72	8.07	8.01	7.93
F2	7.86	8.06	8.14	8.04	8.03	7.96	7.89	8.34	8.20	8.10	7.99	7.81	8.04	8.02	7.96
F3	8.07	7.94	8.01	8.02	8.01	8.08	7.77	8.19	8.23	8.07	7.85	7.81	8.08	7.93	7.92
F4	7.98	7.93	8.18	7.97	8.02	7.99	7.92	8.30	8.21	8.11	7.92	7.88	8.10	8.06	7.99
Mean	7.96	7.97	8.10	7.99	8.01	8.02	7.88	8.26	8.21	8.09	7.92	7.81	8.07	8.01	7.95
	SEm±		CD (P=0.05)			SEm±		CD (P=0.05)			SEm±			CD (P=0.05)	
S	0.01		0.02			0.01		0.04			0.03			0.11	
F	0.01		0.03			0.01		NS			0.02			NS	
S * F	0.02		0.06			0.02		0.07			0.05			NS	

DAT- days after transplanting, GW- groundwater, TSE- treated sewage effluent, USE-untreated sewage effluent

Table 3: Effect of wastewater irrigation and fertilizer levels on soil EC (dS m^{-1})

Fertilizer	30 DAT					60 DAT					At harvest				
levels(F)	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean
F1	0.15	0.18	0.23	0.19	0.19	0.19	0.19	0.26	0.21	0.21	0.17	0.18	0.21	0.22	0.20
F2	0.18	0.19	0.23	0.22	0.21	0.18	0.20	0.24	0.23	0.21	0.14	0.18	0.24	0.22	0.20
F3	0.19	0.20	0.26	0.23	0.22	0.18	0.23	0.27	0.24	0.23	0.16	0.19	0.24	0.21	0.20
F4	0.17	0.18	0.23	0.22	0.20	0.17	0.18	0.26	0.25	0.21	0.16	0.17	0.23	0.20	0.19
Mean	0.17	0.19	0.24	0.22	0.20	0.18	0.20	0.26	0.23	0.22	0.16	0.18	0.23	0.21	0.20
	SEm±		CD (P=0.05)			SEm±		CD (P=0.05)			SEm±		CD (P=0.05)		
S	0.01		0.02			0.01		0.02			0.01		0.04		
F	0.01		0.02			0.01		NS			0.01		NS		
S * F	0.01		NS			0.01		0.03			0.02		NS		

DAT- days after transplanting, GW- groundwater, TSE- treated sewage effluent, USE-untreated sewage effluent

Table 4: Effect of wastewater irrigation and fertilizer levels on soil organic carbon (g kg^{-1})

Fertilizer	30 DAT					60 DAT					At harvest				
levels(F)	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean
F1	6.10	6.18	6.29	6.24	6.20	6.13	6.27	6.37	6.31	6.27	6.12	6.28	6.34	6.30	6.26
F2	6.16	6.38	6.47	6.42	6.36	6.18	6.63	6.74	6.69	6.56	6.18	6.62	6.72	6.70	6.56
F3	6.19	6.55	6.61	6.59	6.49	6.19	6.68	6.84	6.74	6.61	6.20	6.70	6.76	6.71	6.59
F4	6.01	6.07	6.12	6.11	6.08	6.02	6.14	6.23	6.20	6.15	6.03	6.13	6.23	6.21	6.15
Mean	6.12	6.30	6.37	6.34	6.28	6.13	6.43	6.54	6.49	6.40	6.13	6.43	6.51	6.48	6.38
	SEm±		CD (P=0.05)			SEm±		CD (p=0.05)			SEm±		CD (p=0.05)		
S	0.01		0.04			0.01		0.04			0.0023		0.01		
F	0.01		0.03			0.01		0.04			0.0038		0.01		
S * F	0.02		0.06			0.03		0.07			0.01		0.02		

DAT- days after transplanting, GW- groundwater, TSE- treated sewage effluent, USE-untreated sewage effluent

Table 5: Effect of wastewater irrigation and fertilizer levels on soil total carbon (g kg^{-1})

Fertilizer	30 DAT					60 DAT					At harvest				
levels(F)	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean
F1	22.0	23.3	24.7	23.9	23.5	22.1	23.4	24.9	24.0	23.6	23.6	23.4	24.9	24.0	24.0
F2	22.1	23.8	24.6	24.2	23.7	22.9	23.9	24.7	24.2	23.9	22.9	24.00	24.7	24.3	24.0
F3	22.1	23.6	24.8	24.1	23.6	22.1	23. 9	24.9	24.2	23.7	22.1	23.9	24.9	24.2	23.8
F4	22.1	23.2	24.5	23.6	23.4	22.1	23.3	24.5	23.6	23.4	22.1	23.3	24.5	23.7	23.4
Mean	22.1	23.5	24.6	23.9	23.5	22.3	23.5	24.8	24.0	23.7	22.7	23.7	24.8	24.1	23.8
	SEm±		CD (P=0.05)			SEm±		CD (P=0.05)			SEm±		CD (P=0.05)		
S	0.52		NS			0.44		1.5			0.36		1.3		
F	0.51		NS			0.48		NS			0.43		NS		
S * F	1.01		NS			0.96		NS			0.85		NS		

DAT- days after transplanting, GW- groundwater, TSE- treated sewage effluent, USE-untreated sewage effluent

and 0.24 dS m^{-1}, respectively) compared to irrigation with treated sewage effluent (7.97 and 0.19 dS m^{-1}, respectively) at 30 days after transplanting. Groundwater irrigation resulted in lower values of these two parameters. The higher soil pH and electrical conductivity of untreated effluent irrigated soils might be due to the relatively higher pH and soluble salts content of raw sewage effluent than the treated (Table 1). The same trend was observed at 60 days after transplanting and at

Table 6: Effect of wastewater irrigation and fertilizer levels on available B (mg kg^{-1})

Fertilizer			30 DAT					60 DAT					At harvest		
levels(F)	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean
F1	0.84	1.38	1.80	1.53	1.39	0.84	1.80	2.55	2.18	1.84	0.83	1.83	2.33	2.30	1.82
F2	0.77	1.37	1.78	1.77	1.42	0.79	1.53	2.47	2.24	1.76	0.76	1.70	2.25	2.33	1.76
F3	0.77	1.40	1.72	1.76	1.41	0.79	1.60	2.32	2.23	1.74	0.77	1.67	2.31	2.32	1.77
F4	0.75	1.36	1.74	1.79	1.41	0.73	1.69	2.72	2.22	1.84	0.75	1.75	2.24	2.23	1.74
Mean	0.78	1.38	1.76	1.71	1.41	0.79	1.66	2.51	2.22	1.79	0.78	1.74	2.28	2.30	1.77
	SEm±		CD (P=0.05)			SEm±		CD (P=0.05)			SEm±		CD (P=0.05)		
S	0.05		0.16			0.03		0.09			0.03		0.10		
F	0.04		NS			0.04		NS			0.04		NS		
S * F	0.08		NS			0.07		0.22			0.07		NS		

DAT- days after transplanting, GW- groundwater, TSE- treated sewage effluent, USE-untreated sewage effluent

Table 7. Effect of wastewater irrigation and fertilizer levels on exchangeable Ca [cmol (p$^+$) kg^{-1}]

Fertilizer			30 DAT					60 DAT					At harvest		
levels(F)	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean
F1	14.90	17.84	17.97	17.21	16.98	16.01	19.21	20.32	20.28	18.96	14.53	15.30	16.38	16.00	15.55
F2	15.61	18.55	19.47	19.31	18.24	16.59	19.99	21.43	21.26	19.82	14.98	15.81	17.34	16.64	16.19
F3	17.38	19.99	19.86	19.76	19.25	17.18	20.32	22.15	21.96	20.40	15.81	16.70	18.30	16.90	16.93
F4	13.92	15.42	17.25	16.99	15.90	13.85	15.55	17.12	16.53	15.76	13.57	14.53	15.74	15.23	14.77
Mean	15.45	17.95	18.64	18.32	17.59	15.91	18.77	20.26	20.01	18.73	14.72	15.59	16.94	16.19	15.86
	SEm±		CD (P=0.05)			SEm±		CD (P=0.05)			SEm±		CD (P=0.05)		
S	0.45		1.56			0.11		0.39			0.09		0.32		
F	0.17		0.51			0.08		0.24			0.07		0.19		
S * F	0.35		1.01			0.17		0.48			0.13		0.39		

DAT- days after transplanting, GW- groundwater, TSE- treated sewage effluent, USE-untreated sewage effluent

Table 8: Effect of wastewater irrigation and fertilizer levels on exchangeable Na [cmol (p$^+$) kg^{-1}]

Fertilizer			30 DAT					60 DAT					At harvest		
levels(F)	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean
F1	0.91	1.07	1.67	1.62	1.32	0.96	1.90	3.76	2.62	2.31	0.89	1.86	2.40	2.17	1.83
F2	0.99	1.22	1.74	1.51	1.36	1.29	2.20	4.17	3.12	2.70	0.92	1.96	3.37	2.44	2.17
F3	1.32	1.52	1.93	1.64	1.60	1.47	2.37	5.38	3.08	3.07	0.92	2.07	3.19	2.75	2.23
F4	0.86	0.94	1.30	1.36	1.12	0.82	1.55	2.91	2.06	1.83	0.84	1.53	1.55	1.16	1.27
Mean	1.02	1.19	1.66	1.53	1.35	1.14	2.00	4.05	2.72	2.48	0.89	1.86	2.63	2.13	1.88
	SEm. ±		CD (P=0.05)			SEm±		CD (p=0.05)			SEm±		CD (p=0.05)		
S	0.03		0.12			0.02		0.07			0.02		0.07		
F	0.04		0.12			0.02		0.07			0.04		0.11		
S * F	0.08		0.24			0.05		0.14			0.08		0.22		

DAT- days after transplanting, GW- groundwater, TSE- treated sewage effluent, USE-untreated sewage effluent

harvest. The higher pH of raw sewage might be due to contribution from soaps and detergents present in domestic sewage effluent added through washing, bathing *etc.* and also due to presence of higher amount of cations (salts). The higher salt content in plots irrigated with raw sewage was also reported in the literature (Kiziloglu *et al.*, 2008; Mojiri, 2011; Anastasis *et al.*, 2014). The effect of fertilizer levels on soil pH and electrical conductivity was inconsistent.

The soils irrigated with untreated sewage effluent registered significantly higher organic carbon and total carbon in soil (6.37 and 24.6 g kg^{-1}, respectively) compared to treated sewage effluent irrigation (6.30 and 23.5 g kg^{-1}, respectively) at 30 days after transplanting. This was due to higher organic load (total carbon) contained in untreated sewage effluent, further supported by its higher values of biological oxygen demand and chemical oxygen demand (Table 1) than treated sewage effluent. Groundwater irrigated soils recorded considerably lower organic and total carbon compared to sewage irrigated soils (Table 4 and 5). Increase in organic carbon and total carbon in soil due to sewage irrigation has been reported by many researchers (Mojiri, 2011; Bhat, 2011; Alka *et al.*, 2011; Mollahoseini, 2013). Among the interactions, the untreated sewage effluent - F_3 combination recorded higher organic carbon throughout the study period (6.61, 6.84 and 6.76 g kg^{-1}, at 30 and 60 days after transplanting and at harvest, respectively). The reduction in both total and organic carbon content from 60 days after transplanting to harvest might be due to the less frequency of irrigation in this period.

The available boron in soils at 30 and 60 days after transplanting and at harvest was relatively higher (1.76, 2.51 and 2.28 mg kg^{-1}, respectively) under untreated effluent irrigation than plots irrigated with treated sewage effluent (1.38,

Table 9: Effect of wastewater irrigation and fertilizer levels on CEC [cmol (p^+) kg^{-1}]

Fertilizer			30 DAT					60 DAT					At harvest		
levels(F)	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean
F1	20.83	23.55	25.55	23.72	23.41	21.25	25.32	27.02	26.23	24.95	19.71	22.15	23.40	23.13	22.10
F2	21.74	25.00	27.35	24.34	24.61	22.43	26.67	31.26	28.58	27.23	20.85	23.33	26.76	23.41	23.58
F3	22.03	25.42	27.41	25.06	24.98	23.56	25.12	32.06	30.53	27.82	21.51	24.37	27.11	25.17	24.54
F4	19.22	21.38	23.90	23.56	22.01	18.89	21.19	22.81	22.51	21.35	18.50	19.82	21.96	21.26	20.39
Mean	20.95	23.84	26.06	24.17	23.75	21.53	24.58	28.29	26.96	25.34	20.14	22.42	24.81	23.24	22.65
	SEm.±		CD (P=0.05)			SEm±		CD (p=0.05)			SEm±		CD (p=0.05)		
S	0.82		2.84			1.27		4.39			0.57		1.96		
F	0.36		1.05			0.51		1.49			0.24		0.69		
S * F	0.72		NS			1.02		NS			0.47		1.38		

DAT- days after transplanting, GW- groundwater, TSE- treated sewage effluent, USE-untreated sewage effluent

Table 10: Effect of wastewater irrigation and fertilizer levels on ESP

Fertilizer			30 DAT					60 DAT					At harvest		
levels(F)	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	Mean
F1	4.38	4.56	6.57	6.78	5.57	3.26	5.44	10.11	7.53	6.58	4.53	8.40	10.25	9.37	8.14
F2	4.54	4.90	6.41	6.28	5.53	4.22	5.93	9.75	8.45	7.09	4.40	8.42	12.68	10.47	8.99
F3	5.96	6.05	7.10	6.72	6.45	4.58	7.04	12.94	8.51	8.27	4.27	8.52	11.89	10.94	8.90
F4	4.45	4.43	5.48	5.83	5.05	3.19	5.38	9.28	6.73	6.14	4.54	7.74	7.10	5.45	6.21
Mean	4.83	4.98	6.39	6.40	5.65	3.81	5.95	10.52	7.80	7.02	4.44	8.27	10.48	9.06	8.06
	SEm.±		CD (P=0.05)			SEm±		CD (p=0.05)			SEm±		CD (p=0.05)		
S	0.21		0.74			0.96		3.31			0.24		0.84		
F	0.16		0.47			0.28		0.82			0.18		0.52		
S * F	0.33		NS			0.56		NS			0.36		1.04		

DAT- days after transplanting, GW- groundwater, TSE- treated sewage effluent, USE-untreated sewage effluent

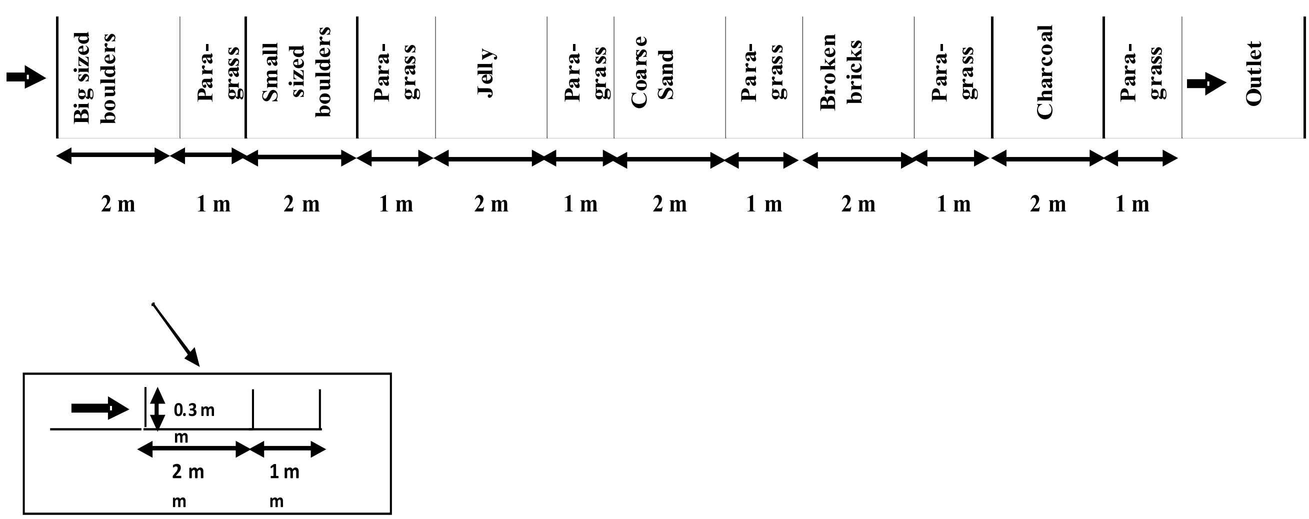

Figure 1: Lay-out of semi-surface horizontal flow constructed wetland components

1.66 and 1.74 mg kg^{-1}, respectively). This was attributed to higher boron content in raw sewage itself (2.14 mg L^{-1}) compared to treated sewage effluent (1.00 mg L^{-1}) (Table 1). The varied fertilizer levels did not influence available boron in soils (Table 6). Even though there was a reduction in the hot water soluble boron concentration in the treated sewage effluent irrigated soils, it was higher than the safe limit set for irrigation emphasizing the need for refining the treatment system for efficient removal of boron. Groundwater irrigated soils recorded least boron content throughout the investigation period.

Exchangeable cations like calcium and sodium were significantly higher in soils irrigated with untreated sewage effluent during the entire period of investigation over rest of the sources of irrigation water (Table 7and 8). Irrigation with treated sewage effluent significantly reduced the accumulation of exchangeable calcium and sodium in the soil at all the stages of sampling. The exchangeable calcium in untreated effluent irrigated soil was 18.64, 20.26 and 16.94 cmol (p^+) kg^{-1} which reduced to 17.95, 18.77 and 15.59 cmol (p^+) kg^{-1} at 30 and 60 days after transplanting and at harvest, respectively. The fertilizer levels had lesser impact on exchangeable cations than the sources of irrigation water. Among the interactions, the untreated sewage effluent-F_3 combination recorded significantly higher exchangeable calcium [19.86, 22.15 and 18.30 cmol (p^+) kg^{-1} soil at 30 and 60 days after transplanting and at harvest, respectively] than others. The observed increase in exchangeable Na content in sewage irrigated plots over groundwater signified the process of sodication taking place in soil due to sewage irrigation. Compared to untreated, the treated effluent irrigation is expected to undergo a slow process of sodication, owing to lower soil exchangeable sodium than the former (Table 8).

Sewage irrigated soils recorded significantly higher cation exchange capacity than groundwater irrigated soils throughout the study period (Table 9). Untreated effluent irrigated soils accounted for significantly higher cation exchange capacity (26.06, 28.29 and 24.81 cmol (p^+) kg^{-1} at 30 and 60 days after transplanting and at harvest, respectively) than treated sewage effluent (23.84, 24.58 and 22.42 cmol (p^+) kg^{-1} at 30 and 60 days after transplanting and at harvest, respectively). This can be ascribed to higher soil organic carbon content and exchangeable cationic concentration associated with untreated sewage effluent than treated (Table 1). The large difference in cation exchange capacity between groundwater and sewage irrigated soils was also largely due to this fact. The fertilizer levels showed a positive trend on cation exchange capacity. In general, plots applied with increased level of fertilizers registered higher value of cation exchange capacity. Similar findings were reported by (Kiziloglu *et al*., 2008; Qishlaqui *et al*., 2008; Bhat, 2011). The cation exchange capacity of all experimental plots were reduced at harvest which might be due to reduced frequency of irrigations and thereby low organic matter addition.

The sources of irrigation water greatly influenced exchangeable sodium percentage than the fertilizer levels (Table 10). The overall exchangeable sodium percentage values across different treatments were within 10 which is considered safe for most soils and crops. Though falling under safe, irrigation with untreated sewage effluent had shown an increase in exchangeable sodium percentage over groundwater irrigation alone. This observation was true at all the three stages of sampling. However, irrigation with treated sewage effluent showed much less exchangeable sodium percentage than the untreated. This signified the importance of sewage treatment before irrigation to reduce the risk of soil sodication. The higher exchangeable sodium percentage in untreated sewage effluent irrigated soils was due to accumulation of more sodium (Table 8) due to successive sewage irrigation. Herpin *et al*. (2011) also reported similar findings wherein sewage irrigation enhanced soil exchangeable sodium percentage over irrigation with normal water.

From this study, it was concluded that the soils irrigated with untreated sewage effluent had the positives of higher accumulation of organic carbon, total carbon, exchangeable cations and cation exchange capacity but the negatives of higher pH, electrical conductivity, boron and exchangeable sodium percentage. However, irrigation with treated sewage effluent showed remedial effects through relatively lower pH, salt content and exchangeable sodium percentage but along with the benefits contained in it. It was imperative that irrigation with domestic wastewater, treated through constructed wetland system was useful in inducting favourable soil physico-chemical conditions. Though, groundwater had lesser values of all these parameters, because of its lesser carbon content it was less nutritive. The combination of raw sewage irrigation along with 100 per cent recommended dose of fertilizers recorded higher values for organic carbon, exchangeable calcium and cation exchange capacity compared to other fertilizer combinations.

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