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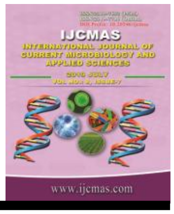

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Studies on the Effect of Treated Sewage Effluent Irrigation on N Dynamics in Soil

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ABSTRACT

An experiment was conducted at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, Karnataka, India during 2014 to study the effect of horizontal constructed wetland treatment of domestic sewage effluent on its quality and effect of its irrigation on soil nitrogen dynamics both temporally and spatially. The analytical results revealed that there was improvement in the quality of sewage effluent after passing through the constructed wetland treatment system which was reflected by reduction in pH, EC, BOD, COD and TSS. A notable reduction in BOD (54 per cent) was observed in treated sewage effluent as compared with that of untreated sewage effluent. The mean BOD of 256 mg L^{-1} in untreated sewage effluent was reduced to 118 mg L^{-1} after the treatment. The groundwater registered the lowest COD of 14 mg L^{-1} among different sources of irrigation water. The mean COD of treated sewage effluent was 251mg L^{-1} as compared with that of 410 mg L^{-1} in untreated sewage effluent. A reduction in total suspended soils to the extent of 42 per cent was observed from 480 to 278 mg L^{-1} after passing through constructed wetland. The constructed wetland system acted as a mechanical and biological filter and removed suspended particles from the water. Sources of irrigation water, fertilizer levels and their interaction had a significant effect on ammoniacal nitrogen (NH_4^+ -N), nitrate nitrogen (NO_3^- -N), organic nitrogen and total nitrogen content in soil. Treated sewage effluent had higher concentration of ammoniacal and nitrate nitrogen than untreated sewage effluent. The soil ammoniacal nitrogen was the dominant inorganic nitrogen form present in the soil. Organic and total nitrogen content in the sewage irrigated plots were significantly superior over groundwater irrigated plots. Among different N fractions, the predominance was in the order of ON > NH_4^+-N > NO_3^- -N.

Keywords

Domestic sewage effluent, Constructed wetland, Treated sewage effluent, Nitrogen dynamics

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Introduction

Increasing demand for freshwater resources has lead to the use of poor quality water such as industrial and domestic wastewater for irrigation. Besides being relatively cheaper than freshwater, wastewater is a valuable and rich source of plant nutrients and organic matter; which is vital for maintenance of soil fertility and productivity. The composition of the sewage water varies widely according to the source of its origin. But in general, sewage water irrespective of the source from where it generates contains large quantities of both macro and micro nutrients. Appreciable amounts of organic load, toxic contaminants such as heavy metals restrict the direct application of sewage water. In order to overcome these harmful effects, treatment of sewage water should be considered. In this study, an artificially constructed wetland system has been employed for the treatment of domestic sewage water from the University campus, Dharwad. Constructed wetland is a wastewater treatment system composed of one or more treatment cells in a built and partially controlled environment, designed and constructed to provide wastewater treatment. Constructed wetland has been used to treat many types of wastewater at various levels of treatment. Natural characteristics are applied to constructed wetlands with emergent macrophyte stands that duplicate the physical, chemical and biological processes of natural wetland systems. The major nutrient removal mechanisms taking place in these treatment systems are biodegradation, precipitation and filtration. It is a cheaper alternative for wastewater treatment using local resources and moreover, it is an eco-friendly system of sewage treatment. Nitrogen represents the nutrient found in larger concentrations in sewage water, occurring predominantly as NH_4^+ - N, with variable proportions of organic nitrogen. The understanding of effluent - N transformation processes in soil in the NO_3^- - N dynamics represents key factors for the sustainable management of sewage water. Several researchers, Rousseau *et al.*, (2004), Rai *et al.*, (2013), Salakinkop and Hunshal (2014), Abdel (2015), Suhad *et al.*, (2017), Manjunatha *et al.*, (2017 a & 2017 b) highlighted the advantages of constructed wetland to treat many types of wastewater and re-use of treated waste water for irrigation in water scarcity areas. Hence, the study has been conducted with the objectives of understanding the dynamics of nitrogen taking place under sewage irrigated conditions as influenced by varied levels of fertilizer applications along with the monitoring of temporal variations in the composition of sewage water.

Materials and Methods

Site description

The soil was red sandy loam in the surface and the subsurface soil was sandy clay loam. The soils were slightly alkaline in nature in both surface (pH 7.95 in 0-20 cm) and subsurface depths (pH 8.05 in 20-40 cm). The surface soil registered low electrical conductivity (0.15 dS m^{-1}) than the underlying soil (0.17 dS m^{-1}).

Organic carbon tends to reduce down the depth. Generally, the soils were medium in organic carbon content. Ammoniacal nitrogen was the dominant inorganic nitrogen form irrespective of the soil depths (14.12 and 12.16 mg kg^{-1} at 0-20 and 20-40 cm, respectively). Surface soil contained higher NO_3^- -N (12.43 mg kg^{-1}) than the subsurface soil (9.34 mg kg^{-1}). Total and organic nitrogen in the topsoil of 0-20 cm depth (371 and 345 mg kg^{-1}, respectively) were fairly higher than in the lower soil depth of 20-40 cm (284 and 263 mg kg^{-1}, respectively).

Design of horizontal flow constructed wetland

The sewage effluent was treated by passing through horizontal surface flow wetland system. The dimension of the treatment unit was 29 m length x 1m width x 0.3 m deep. The filtering materials used were stone boulders (big and small), jelly, sand, broken bricks and charcoal. The grassed (*Brachiaria mutica*) channel was sequentially bedded with 2.0 m length strips each of big sized boulders (30 - 45 mm size), small sized boulders (25-30 mm size), jelly (~ 20 mm size), sand (0.25 mm 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. The discharge rate was measured to be 2 to 5 liters sec^{-1}. The domestic sewage was allowed to flow through treatment plant from inlet and the treated wastewater was collected in outlet and used for irrigation.

Experimental details

The study emphasized to assess the influence of fertilizer levels coupled with sewage effluent irrigation on the nitrogen transformation taking place in the soil planted with tomato crop (cv Abhilasha) spatially as well as temporally. The experiment was laid out in a split plot design with four irrigation sources *viz*. groundwater (GW), treated sewage effluent (TSE), untreated sewage effluent (USE) and untreated sewage effluent alternately irrigated with groundwater (USE - GW) as main plots and four fertilizer levels *viz*., 50 per cent recommended doses of N, P_2O_5 and K_2O + bio-fertilizers (F_1), 75 per cent recommended doses of N, P_2O_5 and K_2O + bio-fertilizers (F_2), RDF alone; no bio-fertilizers (F_3) and no fertilizers (F_4) as sub-plots. The RDF for tomato crop is 250:250:250 kg of N, P_2O_5 and K_2O ha^{-1}, respectively. With respect to F_1 and F_2, 25 per cent of N and K_2O and 50 per cent of P_2O_5 was applied as basal dose and remaining quantity of N and K_2O was applied in three equal splits at 25 DAT, 45 DAT and 65 DAT. Remaining 50 per cent of P_2O_5 applied at 20-25 DAT.

With respect to F_3, 50 per cent of N, 100 per cent P_2O_5 and 100 per cent K_2O was applied at the time of transplanting and the remaining 50 per cent N was applied as top dressing 4 weeks after transplanting. The water samples were collected periodically at 7 days interval whereas the soil samples were collected at 30 and 60 days after transplanting and at time of harvest of tomato crop in two depths *viz*., 0-20 and 20-40 cm, respectively.

Laboratory analysis

Both untreated sewage effluent (USE) and treated sewage effluent (TSE) were analyzed for irrigation water quality parameters *viz.*, pH, electrical conductivity (EC), biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS). These were also analyzed for forms of N *viz.*, ammoniacal nitrogen (NH_4^+ - N), nitrate nitrogen NO_3^- -N, organic nitrogen (ON), total nitrogen (TN) and total phosphorus (TP) by following the procedures as described by APHA (1998) and was compared with that of groundwater (GW). The ammoniacal, nitrate, organic and total nitrogen forms present in soil as influenced by fertilizers and sewage irrigation were analysed by using standard procedures as described by Page *et al.*, (1982).

Results and Discussion

Characterization of sewage effluent

The mean pH of the untreated sewage effluent was slightly alkaline in nature (7.33) which might be due to contribution from soaps and detergents present in domestic sewage effluent added through washing, bathing etc. (Table 1). The pH of treated sewage effluent registered lower values compared to untreated sewage effluent throughout the experimental period. The observed pH reduction was attributed to CO_2 production from decomposing plant litter and other sewage effluent components trapped in the root mat and nitrification of ammonia. These results are in agreement with the findings of Li *et al.*, (2008) and Fan *et al.*, (2013). The mean pH of treated sewage effluent was found to be 6.88 which remained on par with the pH of groundwater (6.91).

In general, the electrical conductivity of the raw sewage effluent was higher throughout the experimental period compared with the treated sewage effluent which was collected from the outlet of the constructed wetland treatment system. The overall mean EC of untreated sewage effluent (USE) was 0.83 dS m^{-1}, whereas it was 0.76 dS m^{-1} for treated sewage effluent (TSE). The decrease in conductivity was attributed to uptake of micro and macro elements and ions by plants and bacteria and their removal through adsorption to plant roots, litter and settle able suspended particles. Similar findings were reported by Vera *et al.,* (2011) and Arivoli and Mohanraj (2013). The EC of groundwater was relatively low (0.72 dS m^{-1}) compared to that of USE and TSE (Table 1).

A reduction in total suspended soils was observed from 480 to 278 mg L^{-1} after constructed wetland treatment (Table 1). Efficiency of constructed wetland in the removal of turbidity is reported to depend largely on the size of sand/ bedding particles and the depth of the bed. The constructed wetland system acted as a mechanical and biological filter and removed suspended particles from the water. The results were in accordance with the findings of Jing *et al.,* (2001), Zurita *et al.,* (2009) and Vera *et al.,* (2011).

A notable reduction in BOD (54 per cent) of treated sewage effluent was observed as compared with that of untreated sewage effluent. The mean BOD of 256 mg L^{-1} in USE was reduced to 118 mg L^{-1} after the treatment (Table 1). These trends are in agreement with the findings of Zurita *et al.,* (2009) who reported a considerable reduction in BOD due to constructed wetland system. The groundwater recorded the lowest BOD of 9 mg L^{-1}.

The COD of treated sewage effluent varied from 236 to 268 mg L^{-1} with the mean value of 251mg L^{-1} as compared with that of 410 mg L^{-1} in USE. The groundwater registered the lowest COD of 14 mg L^{-1} among different sources of irrigation water used in the present study (Table 1). The presence of macrophytes as a bio-filter is reported to provide a more effective distribution of the roots and a more propitious habitat encouraging the development of a great diversity of microbial communities. Higher BOD and COD removal efficiencies were reported due to increased retention time and higher rhizhosphere oxidation caused by diversity of roots.

In contrast to other parameters, NH_4^+-N concentration in the USE was less (14.5 mg L^{-1}) than that in the TSE (16.6 mg L^{-1}) throughout the experimental period. The NH_4^+ -N concentrations in the USE ranged from 13.4 to 16.4 mg L^{-1} while that in TSE varied between 14.6 and 17.6 mg L^{-1} (Table 1). The results obtained were contrasting to the findings of Arivoli and Mohanraj (2013), Vera *et al.,* (2011) and Jing *et al.,* (2001). But, Vymazal (2011) reported that removal of ammonia-N is limited by lack of dissolved oxygen in filtration beds caused by permanent saturation. Moreover, in domestic sewage effluent, organic nitrogenous fractions will be more. Because of the enhanced bacterial action taking place in a constructed wetland, the organic nitrogen might be converted into ammoniacal nitrogen, which further because of the phenomenon of matrix adsorption might be coming back to the treated water. Ammoniacal-N is known to get adsorbed onto active sites of the bed matrix. Since it is a reversible process, as the cation exchange site of matrix is saturated, NH_4^+ -N will be released back into the water system. The higher NO_3^- -N content in the treated water (2.99 mg L^{-1}) might be because of the enhanced rhizosphere microbial activity under the plant species in the wetland treatment unit as compared with that of 1.69 and 0.75 mg L^{-1} in USE and GW, respectively.

The USE recorded higher organic and total nitrogen concentration compared to TSE.

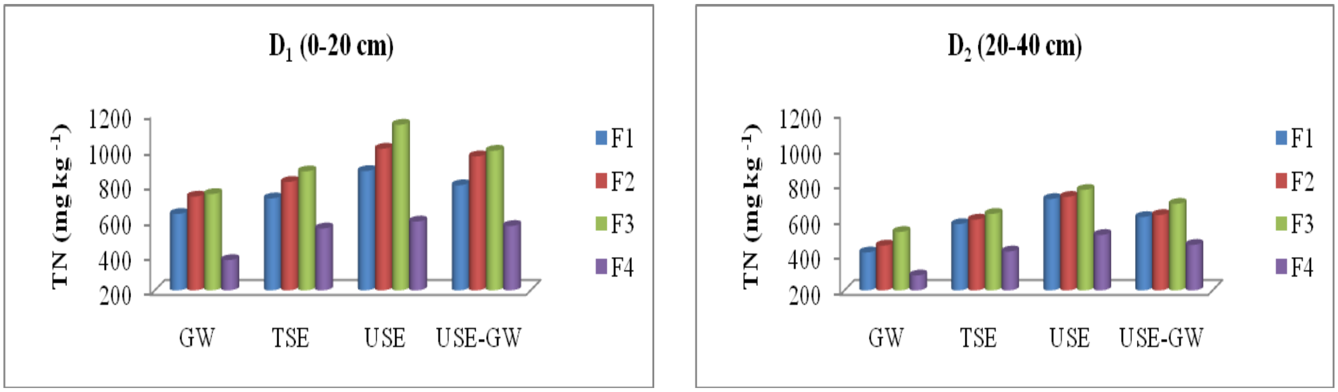

Fig.1a Effect of sewage irrigation and fertilizer levels on total –N in soil at 30 DAT

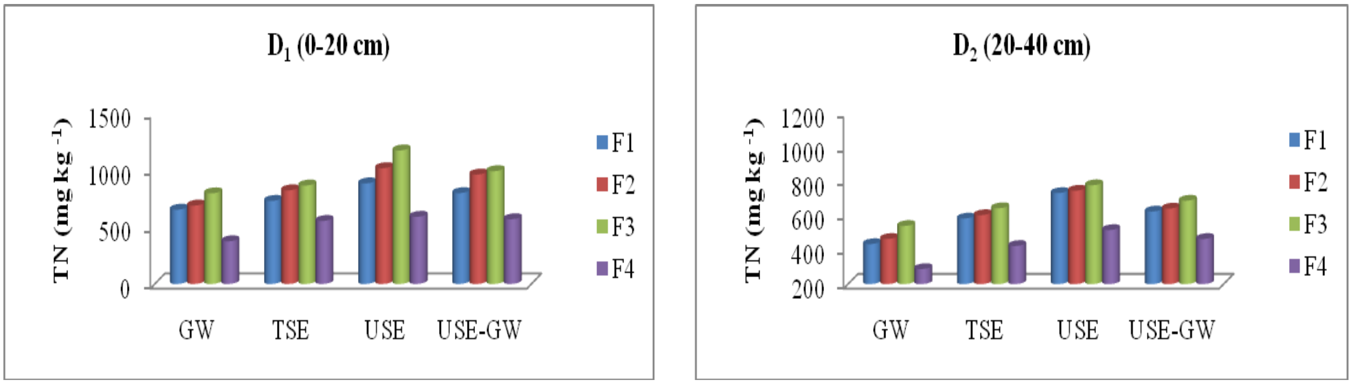

Fig.1b Effect of sewage irrigation and fertilizer levels on total –N in soil at 60 DAT

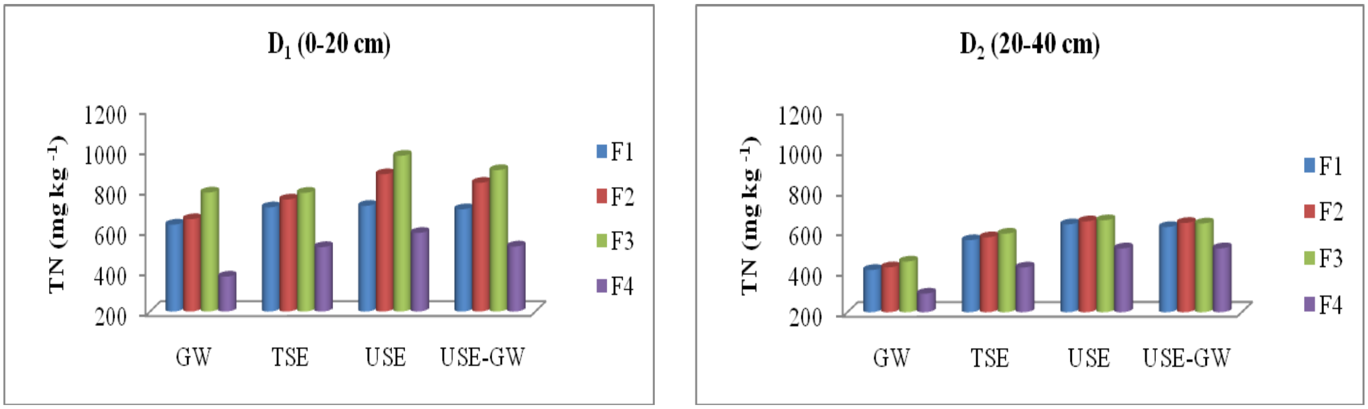

Fig.1c Effect of sewage irrigation and fertilizer levels on total –N in soil at harvest

Table.1 Physico-chemical parameters and nutrient composition of untreated, treated sewage effluent and ground water

Parameters	**Jan. 2014**		**Feb. 2014**		**Mar. 2014**		**Apr. 2014**		**May, 2014**		**Overall mean**		**GW**
	USE	TSE	USE	TSE	USE	TSE	USE	TSE	USE	TSE	USE	TSE	
1. pH	7.62	7.24	6.71	6.63	7.86	7.43	7.22	6.41	7.26	6.68	7.33	6.88	6.91
2. EC (dS m^{-1})	0.76	0.75	0.88	0.76	0.87	0.85	0.77	0.74	0.88	0.69	0.83	0.76	0.72
3. Total suspended solids (mg L^{-1})	420	290	480	230	390	250	480	270	630	350	480	278	8
4. BOD (mg L^{-1})	252	113	259	121	268	119	252	116	249	123	256	118	9
5. COD (mg L^{-1})	416	241	412	256	402	236	441	253	410	268	410	251	14
6. NH_4^+- N (mg L^{-1})	13.4	17.4	15.5	16.4	13.9	14.6	13.4	17.2	16.4	17.6	14.5	16.6	0.46
7. NO_3^- - N (mg L^{-1})	1.40	3.82	1.23	1.33	2.28	3.34	1.48	3.23	2.06	3.23	1.69	2.99	0.75
8. Organic nitrogen (mg L^{-1})	8.26	1.35	5.10	2.81	7.72	2.59	10.84	1.85	9.49	1.77	8.28	2.07	0.003
9. Total nitrogen (mg L^{-1})	23.1	22.6	21.8	20.5	23.9	20.5	25.7	22.3	23.9	22.6	23.7	21.7	1.25
10. Total phosphorous (mg L^{-1})	9.1	5.9	11.1	9.3	7.5	4.8	5.7	4.2	6.3	5.9	7.94	6.02	0.10

USE, untreated sewage effluent; TSE, treated sewage effluent; GW, groundwater

Table.2a Effect of sewage irrigation and fertilizer levels on ammoniacal –N (mg kg^{-1}) in soil at 30 DAT

Fertilizer levels (F)	**Soil depth (0-20 cm)**					**Soil depth (20-40 cm)**				
	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	**Mean**
F_1	25.57	40.37	43.57	35.67	36.29	16.80	28.07	28.83	22.37	**24.02**
F_2	28.13	46.10	48.83	39.53	40.65	18.80	31.53	32.43	25.60	**27.09**
F_3	31.60	50.10	49.73	43.43	43.72	21.00	33.10	33.10	27.03	**28.56**
F_4	14.27	19.87	19.83	16.97	17.73	12.23	16.33	16.27	13.97	**14.70**
Mean	28.43	45.52	47.38	39.54	34.60	18.87	30.90	31.46	25.00	**23.59**
	SEm.±		CD (P=0.05)			SEm.±		CD (P=0.05)		
S	0.14		0.48			0.25		0.88		
F	0.18		0.51			0.21		0.62		
S x F	**0.35**		**1.03**			**0.42**		**1.24**		

Table.2b Effect of sewage irrigation and fertilizer levels on ammoniacal –N (mg kg^{-1}) in soil at 60 DAT

Fertilizer levels (F)	**Soil depth (0-20 cm)**					**Soil depth (20-40 cm)**				
	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	**Mean**
F_1	26.07	49.27	44.03	37.50	39.22	18.03	29.30	29.30	23.27	**24.98**
F_2	28.17	51.40	49.57	40.80	42.48	19.87	34.20	33.53	26.97	**28.64**
F_3	32.60	56.90	52.47	44.20	46.54	21.77	35.63	35.53	29.43	**30.59**
F_4	14.43	20.47	20.97	17.63	18.38	12.47	18.37	18.17	14.90	**15.98**
Mean	28.94	52.52	48.69	40.83	36.66	19.89	33.04	32.79	26.56	**25.05**
	SEm.±		CD (P=0.05)			SEm.±		CD (P=0.05)		
S	0.34		1.17			0.22		0.75		
F	0.47		1.37			0.16		0.47		
S x F	**0.94**		**2.74**			**0.32**		**0.93**		

Table.2c Effect of sewage irrigation and fertilizer levels on ammoniacal –N (mg kg^{-1}) in soil at harvest

Fertilizer levels (F)	**Soil depth (0-20 cm)**					**Soil depth (20-40 cm)**				
	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	**Mean**
F_1	22.40	40.40	39.97	33.50	34.07	16.27	25.40	24.33	21.83	**21.96**
F_2	22.30	40.57	40.00	33.40	34.07	18.47	25.30	24.77	22.87	**22.85**
F_3	22.50	40.00	40.23	33.27	34.00	18.63	25.37	25.10	23.07	**23.04**
F_4	14.47	18.67	18.53	16.67	17.08	12.13	16.07	15.97	13.97	**14.53**
Mean	22.40	40.32	40.07	33.39	29.81	17.79	25.36	24.73	22.59	**20.60**
	SEm.±		CD (P=0.05)			SEm.±		CD (P=0.05)		
S	0.33		1.15			0.11		0.37		
F	0.35		1.02			0.12		0.36		
S x F	**0.70**		**2.05**			**0.25**		**0.73**		

DAT, days after transplanting; S, sources of irrigation water; F, Fertilizer levels; GW, groundwater; TSE, treated sewage effluent; USE, untreated sewage effluent.

Table.3a Effect of sewage irrigation and fertilizer levels on nitrate –N (mg kg^{-1}) in soil at 30 DAT

Fertilizer levels (F)	**Soil depth (0-20 cm)**					**Soil depth (20-40 cm)**				
	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	**Mean**
F$_1$	20.23	39.77	37.43	31.70	32.28	17.63	21.20	20.30	20.33	**19.87**
F$_2$	21.97	42.77	42.47	37.47	36.17	18.70	22.77	21.77	21.07	**21.08**
F$_3$	28.57	48.23	44.87	41.43	40.78	20.13	24.53	24.37	22.47	**22.88**
F$_4$	12.67	19.57	19.37	16.63	17.06	9.57	18.33	18.63	16.97	**15.88**
Mean	20.86	37.58	36.03	31.81	31.57	16.51	21.71	21.27	20.21	**19.92**
	SEm.±		CD (P=0.05)			SEm.±		CD (P=0.05)		
S	0.16		0.57			0.20		0.70		
F	0.25		0.74			0.20		0.59		
S x F	**0.51**		**1.48**			**0.40**		**1.18**		

Table.3b Effect of sewage irrigation and fertilizer levels on nitrate –N (mg kg^{-1}) in soil at 60 DAT

Fertilizer levels (F)	**Soil depth (0-20 cm)**					**Soil depth (20-40 cm)**				
	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	**Mean**
F$_1$	22.47	43.70	38.17	34.93	34.82	18.83	36.50	35.77	27.20	**29.58**
F$_2$	24.67	45.43	44.37	37.63	38.03	19.67	39.43	38.87	30.47	**32.11**
F$_3$	26.47	47.60	44.80	42.93	40.45	21.80	40.73	39.97	33.50	**34.00**
F$_4$	12.77	21.03	20.60	17.97	18.09	9.77	19.47	19.27	17.33	**16.46**
Mean	21.59	39.44	36.98	33.37	32.85	17.52	34.03	33.47	27.13	**28.04**
	SEm.±		CD (P=0.05)			SEm.±		CD (P=0.05)		
S	0.27		0.95			0.12		0.43		
F	0.23		0.67			0.27		0.77		
S x F	**0.46**		**1.35**			**0.53**		**1.55**		

Table.3c Effect of sewage irrigation and fertilizer levels on nitrate –N (mg kg^{-1}) in soil at harvest

Fertilizer levels (F)	**Soil depth (0-20 cm)**					**Soil depth (20-40 cm)**				
	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	**Mean**
F$_1$	19.87	38.73	37.20	27.97	30.94	17.49	32.20	32.47	26.10	**27.07**
F$_2$	20.10	38.73	37.23	27.73	30.95	17.45	33.07	32.77	27.43	**27.68**
F$_3$	21.07	37.44	36.67	26.63	30.45	16.63	32.77	32.80	28.23	**27.61**
F$_4$	12.43	19.53	19.07	16.40	16.86	9.70	18.23	18.38	16.63	**15.74**
Mean	18.37	33.61	32.54	24.68	27.30	15.32	29.07	29.10	24.60	**24.52**
	SEm.±		CD (P=0.05)			SEm.±		CD (P=0.05)		
S	0.17		0.59			0.21		0.73		
F	0.26		0.75			0.24		0.71		
S x F	**0.51**		**1.50**			**0.49**		**1.42**		

DAT, days after transplanting; S, sources of irrigation water; F, Fertilizer levels ; GW, groundwater; TSE, treated sewage effluent; USE, untreated sewage effluent.

Table.4a Effect of sewage irrigation and fertilizer levels on organic –N (mg kg^{-1}) in soil at 30 DAT

Fertilizer levels (F)	**Soil depth (0-20 cm)**					**Soil depth (20-40 cm)**				
	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	**Mean**
F_1	587	641	795	728	688	381	526	668	573	**537**
F_2	681	725	911	882	799	417	547	675	580	**555**
F_3	686	776	1044	906	853	490	576	712	641	**604**
F_4	345	511	551	531	484	263	386	479	427	**389**
Mean	651	714	917	838	688	429	549	685	598	**521**
	SEm.±		CD (P=0.05)			SEm.±		CD (P=0.05)		
S	19.5		67.5			3.5		12.1		
F	16.1		47.2			3.6		10.5		
S x F	**32.3**		**94.5**			**7.2**		**21.0**		

Table.4b Effect of sewage irrigation and fertilizer levels on organic –N (mg kg^{-1}) in soil at 60 DAT

Fertilizer levels (F)	**Soil depth (0-20 cm)**					**Soil depth (20-40 cm)**				
	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	**Mean**
F_1	606	638	803	728	694	393	504	659	563	**530**
F_2	638	728	925	885	794	420	519	664	574	**544**
F_3	739	763	1078	906	872	492	556	694	612	**589**
F_4	349	513	550	534	487	266	383	477	429	**389**
Mean	661	709	936	840	711	435	526	672	583	**513**
	SEm.±		CD (P=0.05)			SEm.±		CD (P=0.05)		
S	15.6		53.8			1.7		5.8		
F	14.1		41.1			3.2		9.5		
S x F	**28.2**		**82.2**			**6.5**		**18.9**		

Table.4c Effect of sewage irrigation and fertilizer levels on organic –N (mg kg^{-1}) in soil at harvest

Fertilizer levels (F)	**Soil depth (0-20 cm)**					**Soil depth (20-40 cm)**				
	GW	TSE	USE	USE-GW	Mean	GW	TSE	USE	USE-GW	**Mean**
F_1	587	636	646	644	628	375	498	578	573	**506**
F_2	614	675	802	776	717	386	512	592	591	**520**
F_3	745	710	893	839	797	415	530	597	587	**532**
F_4	345	480	551	489	466	270	387	481	485	**406**
Mean	649	674	780	753	652	392	514	589	584	**491**
	SEm.±		CD (P=0.05)			SEm.±		CD (P=0.05)		
S	5.1		17.7			3.5		12.1		
F	4.6		13.5			2.2		6.5		
S x F	**9.23**		**27.0**			**4.5**		**13.0**		

DAT, days after transplanting; S, sources of irrigation water; F, Fertilizer levels ; GW, groundwater; TSE, treated sewage effluent; USE, untreated sewage effluent.

The mean organic nitrogen content was considerably higher in USE (8.28 mg L^{-1}) followed by TSE (2.07 mg L^{-1}) and least in the GW (0.003 mg L^{-1}). The temporal mean value of total nitrogen was relatively higher in USE (23.7 mg L^{-1}) compared to TSE (21.7 mg L^{-1}) while, groundwater registered the lowest total nitrogen content (1.25 mg L^{-1}) (Table 1). Accelerated bacterial action taking place in a constructed wetland may have major responsible role in reduced organic nitrogen levels in the treated sewage effluent.

The total phosphorous concentration in USE varied greatly between 5.70 and 11.1 mg L^{-1} with the mean value of 7.94 mg L^{-1}. Similarly, the total phosphorous content varied from 4.2 to 9.3 mg L^{-1} with the mean value of 6.02 mg L^{-1} in TSE (Table 1). The total phosphorous concentration in the groundwater was very less (0.10 mg L^{-1}). The processes like precipitation, plant uptake and adsorption taking place in the constructed wetland treatment system might be responsible for the reduction in total phosphorous in the treated sewage effluent (Vera *et al.*, 2011; Arivoli and Mohanraj, 2013).

Effect of sewage irrigation and fertilizer levels on nitrogen dynamics in soil

Ammoniacal nitrogen in soil

Sources of irrigation water, fertilizer levels and their interaction had a significant effect on ammoniacal nitrogen (NH_4^+ -N) content (Tables 2 a, b and c). The surface soil registered relatively higher ammoniacal nitrogen concentration than the subsoil during the course of investigation. The ammoniacal nitrogen showed a decreasing trend with depth which could be attributed to the low rate of mineralization in the deeper layers. Hong *et al.*, (2013) observed higher concentrations of NH_4^+ -N in the top soils. The elevated concentration of ammoniacal nitrogen in the TSE irrigated plots compared to rest of the treatments was due to higher NH_4^+ -N concentration in the TSE. The ammoniacal nitrogen was consistently higher than nitrate nitrogen due to its close relationship with organic carbon and also due to an association of nitrogen with organic matter (Verma *et al.*, 1980). The sharp increase in the NH_4^+ -N concentration at 60 days after transplanting particularly in the sewage effluent irrigated soils might be due to the combined effect of fertilizer application coupled with continuous sewage water irrigation. But, at harvest less frequent irrigations coupled with dilution effect of rain water might have reduced the NH_4^+ -N concentration in the soils.

Nitrate nitrogen in soil

Similar to ammoniacal nitrogen, nitrate nitrogen (NO_3^- -N) status in the experimental plots were significantly influenced by irrigation water sources and fertilizer levels and even their interactions in both the depths (Tables 3 a, b and c). The nitrate nitrogen content was higher in the surface than underlying depth due to rapid transformation of ammoniacal nitrogen to nitrate nitrogen under adequate soil moisture. Sewage effluent irrigated soils had elevated contents of nitrate nitrogen compared to groundwater irrigated soils regardless of graded doses of fertilizers.

The results were in accordance with the findings of Hong *et al.*, (2013) and Fonseca *et al.*, (2007). The TSE contained more nitrate nitrogen than USE and GW; that might have attributed to the relatively higher concentration of nitrate nitrogen in the treated sewage effluent irrigated soils.

Organic nitrogen in soil

The sources of irrigation water and fertilizer levels and their interaction had a significant effect on organic nitrogen content in soils (Tables 4 a, b and c). There was accumulation of organic N in the sewage effluent irrigated soils compared to groundwater irrigated soils. Under all the experimental situations, higher organic N was observed in the surface soils. This is because organic N is closely associated with organic matter which accumulated more in surface soil due to continuous sewage irrigation.

Irrigation with USE accounted for higher organic N content than treated sewage effluent and groundwater irrigated soils.

Total nitrogen in soil

The sources of irrigation water, fertilizer levels as well as their interactions had a significantly pronounced effect on total nitrogen (TN) in all the soil depths (Fig.1 a, b and c). There was a decrease in the total nitrogen content from surface to down the depth. This was ascribed to the close association between organic carbon and nitrogen and adsorption of ammoniacal nitrogen on humus complex in the soil (Verma *et al.,* 1980). The distribution of total N was reported to be dominantly controlled by organic carbon (Paramasivam and Breitenbeek, 1994). The untreated sewage effluent contained more organic matter than groundwater and even treated sewage effluent (data not shown), which coupled with fertilizer application. This might have contributed for the relatively higher total nitrogen content in the USE irrigated soils. Similar result was reported by Fonseca *et al.,* (2007). Less frequent irrigations at harvest might be the reason for low total nitrogen content of the soils in general.

The constructed wetland treatment system improved the quality of sewage effluent with significant reduction in pH, EC, TSS, BOD, COD, TN, ON and TP. However the system was effective in enhancing the rate of mineralization of organic nitrogen. In general, the soils irrigated by both TSE and USE had higher inorganic nitrogen fractions (NH_4^+ and NO_3^- -N). Among the fertilizer levels, application of 75 per cent RDF + Bio fertilizer (F_2) and 100 per cent RDF (F_3) resulted in higher concentrations of NH_4^+ -N and NO_3^- -N over 50 per cent RDF + Bio fertilizer (F_1) and control (F4, no fertilizer application). The surface soil showed higher accumulation of NH_4^+ -N and NO_3^- -N which decreased with depth. In general, higher NH_4^+-N and NO_3^- -N concentrations were observed in TSE – 100 per cent RDF combinations over other interactions. Among different N fractions, the predominance was in the order of ON > NH_4^+-N > NO_3^- -N. The total nitrogen and organic nitrogen concentrations were significantly higher in USE irrigated soils compared to other sources, irrespective of the level of fertilizer and soil depth. The groundwater irrigated soils recorded significantly lower organic and total nitrogen.

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