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Chemical, biochemical, and biological impact of untreated domestic sewage water use on Vertisol and its consequences on wheat (*Triticum aestivum*) productivity

J. K. Saha · N. Panwar · Ajay Srivastava · A. K. Biswas · S. Kundu · A. Subba Rao

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Abstract In the peri-urban areas of central India, sewage water is a valuable resource for agricultural production. In this study, impact of domestic sewage water irrigation for 5 years on Vertisol with no previous history of sewage irrigation was investigated in an ongoing field experiment at Bhopal (India) under subtropical monsoon type climate. The wheat (*Triticum aestivum*) crop was grown during post-rainy winter season with 30 cm of irrigation (groundwater or sewage water) and four nutrient treatments (T_1, 0; T_2, 100%; T_3, 50%; and T_4, 50% of general recommended doses of NPK + FYM at 10 Mg/ha). Results showed that sewage irrigation of about 150 cm over a period of 5 years resulted significant increases in salinity as well as available fractions of N, P, K, and micronutrients, viz., Zn, Fe, and Mn in soils. Carbon and phosphorus applied through sewage water were accumulated more in subsoil layer compared to topmost plough layer. Soil microbiological activity, as indicated by soil respiration, microbial biomass C, as well as dehydrogenase enzyme activity was higher in sewage water-irrigated soils. There was also significant increase in fungal and actinomycetes as well as total coliform population in such soils. Nutrients supplied through sewage water were not able to raise the productivity of wheat to the level that obtained through fertilizers at the recommended level which indicated that additional nutrients through fertilizers are required to obtain higher productivity of wheat under sewage farming. Protein and Zn content in wheat grains were more when the crop was grown with sewage irrigation. Overall results show that except for increase in coliform population, short duration (5 years) of municipal sewage water irrigation did not have any appreciable harmful effect on soil quality as well as crop productivity; rather, it proved beneficial in improving soil fertility, wheat productivity, and produce quality.

Keywords Sewage irrigation · Vertisol · Nutrients · Soil enzyme · Microbial population · Wheat

Introduction

The rapidly expanding urban communities are producing an increasing amount of sewage effluent. This has been used for irrigation in agriculture worldwide since the last century; as it is cheap to dispose such effluents in this way and provides water and nutrients for crops. Most cities in developing countries like India have large numbers of open and covered channels which carry a mixture

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J. K. Saha (✉) · N. Panwar · A. Srivastava ·
A. K. Biswas · S. Kundu · A. S. Rao
Indian Institute of Soil Science, Nabibagh,
Berasia Road, Bhopal, 462038, India
e-mail: jk_saha12000@yahoo.com

of wastewater generated by domestic, municipal, and industrial activities. Farmers in the peri-urban area who live nearby such water sources divert this untreated wastewater for irrigation whenever needed as it proves to be low-cost alternative to conventional irrigation water. It supports livelihood and generates considerable value in urban and peri-urban agriculture of India, despite the health and environmental risks associated with this practice. Besides water for irrigation, farmers are also benefited from high plant nutrient content in the sewage water as they incur no or little investment in fertilizer purchase. In Hyderabad declaration (IWMI 2002), researchers from 18 countries recognized that wastewater (raw, diluted, or treated) is a resource of increasing global importance, particularly in urban and peri-urban agriculture. Such land application of domestic waste water is gaining momentum owing to the fact that land application provides primary, secondary, and tertiary treatment to waste in a single operation, with recycling and reuse benefits of wastewater and nutrients for biomass production (Idelovitch and Michael 1984; Smith and Schroeder 1985), besides preventing the pollution of streams and lakes.

Untreated wastewater, flowing through a natural seasonal creek toward northeast of Bhopal City of India (with about 1.5 million population) is used for irrigation to the lands near it. Although the area receives good amount of rainfall, almost all of it flows down to rivers and lakes leaving little for irrigation during the rest of the months. Availability of groundwater in the area is insufficient even for drinking water, and hence, utilization of it as a source of irrigation is either impossible or costly. Hence, sewage water as a source of irrigation is getting popular, and farmers are even pumping this to newer areas, kilometers away from the sewage-carrying creek. As new areas are being introduced under sewage farming due to rapid expansion of city areas in highly populous countries like India, information is required on the dynamics of changes in soil properties due to introduction of such untreated domestic waste water and a need for nutrient management technology for the farmers growing crops under such system. Several investigations have been carried out on long-term sewage-irrigated areas on the effect of input of organics, nutrients, and salts through wastewater irrigation (Siebe 1998; Friedel et al. 2000; Ryan et al. 2006; Kakar et al. 2006; Bhise et al. 2007; Ghafoor et al. 2004). However, conclusions from these investigations were made by comparing with the places those that are generally far away from sewage-irrigated farms with possible variations in land topography, soil characteristics, cropping, irrigation, and fertilization history. Keeping these in view, a field experiment was initiated in the year 2002–2003 on a cropped land about 4 km away from untreated sewage carrying channel. Although this experiment has been planned for long duration, the impact on soil chemical and biological properties was investigated after 5 years of sewage irrigation.

Methodology

Background information about the experimental site

Experimental site lies in Vertisol (Typic Haplustert) area at the farm of the Indian Institute of Soil Science, Bhopal (77°27′ E and 23°20′ N at 495 m above mean sea level), with no history of sewage irrigation and having subtropical monsoon type climate (mean annual precipitation 1086 mm) with hot summer (maximum day temperature 35–42°C) and mild winter (minimum night temperature 10–17°C). About 90% of the annual precipitation is received during mid-June to mid-September. Soils of the experimental site are alkaline in reaction with a heavy texture. Some of the soil physical and chemical properties of the soil profile are given in Table 1.

Experimental treatments

Field experiment was initiated during the winter season of 2002 on wheat (*Triticum aestivum*)—soybean (*Glycine max*) cropping system. Wheat (var. WH-147) was grown after soybean during the winter months (November–March) with six irrigations of 5 cm each (including one pre-sowing irrigation). The crop was grown with two irrigation treatments (W_1, groundwater and W_2, sewage water) and four nutrient treatments (T_1, 0; T_2,

Table 1 Some of the physical and chemical properties of the vertisol profiles of the experimental area

Soil depth interval (cm)	Particle size fractions (%) 2–0.05 mm	0.05–0.002 mm	<0.002 mm	Bulk density (g/cm^3)	pH	$CaCO_3$ (%)	BS[a] (% CEC)	Exch. Ca (% of BS)	Organic C (g/kg)
0–15	7.5	37.0	55.5	1.58	7.6	2.6	97.6	60.1	5.1
15–30	9.6	33.8	56.6	1.70	7.8	2.6	95.5	60.3	4.1
30–45	8.5	35.0	56.5	1.88	7.8	2.7	96.4	60.5	3.3
45–60	8.0	35.0	57.0	1.80	7.8	2.6	98.0	60.9	3.1
60–75	8.1	35.4	56.5	1.72	7.8	2.6	98.3	60.2	3.4
75–90	12.5	29.5	58.0	1.80	7.9	2.6	94.5	54.3	3.3

[a] Base saturation in percent of cation exchange capacity

100%; T_3, 50%; and T_4, 50% of general recommended doses of NPK + FYM at 10 Mg/ha) with three replications. Recommended dose of fertilizer for wheat was 120 kg N, 26 kg P, and 50 kg K/ha. Soybean (var. JS 335) was grown rainfed during rainy season with general recommended doses of fertilizers (20 kg N, 25 kg P, and 30 kg K/ha).

Characteristics of sewage water

Sewage water samples were analyzed for different chemical parameters following standard methods (Greenberg et al. 1992). Heavy metal concentrations in the water samples were determined with the help of Polarographic analyzer (Radiometer make, TraceLab which includes MDE150 and POL150) using HMDE technique. Chromium was determined with inductively coupled plasma-optical emission spectrophotometer (ICP-OES).

Sewage water used as irrigation in this experiment was, on an average, nearly neutral in reaction (pH 7.4), non-saline (EC, 0.83 mS/cm) and with low sodium hazard (SAR: 3.67). The groundwater used in the experiment was lower in EC (0.57 mS/cm) and SAR values (0.98) than sewage water. Total organic C, N, P, and K contents in the sewage water were, on an average, 214, 27, 22, and 23 mg/L. Average contents of heavy metals like Zn, Cu, Pb, Cd, Cr, and Ni were, respectively, 70, 15, 11, 1, 27, and 15 μg/L.

Sampling of soil and plant parts

Soil samples were taken from maximum rooting zone depth at two layers (0–15 and 15–30 cm) with screw auger from six places of each plot and were pooled. Samples were air-dried, the roots removed, ground, and sieved (2 mm) before chemical analysis. Soil enzyme activities were measured in field moist samples.

Flag leaves of wheat plant were collected during panicle emergence, washed with acidic water (0.05 M HCl) followed by distilled water and dried at 70°C for 24 h. At harvesting stage, aboveground biomass was collected; grains were separated, washed, and dried separately as above.

Analytical methods

Electrical conductivity and pH were estimated in 1:2 soil/water extract by routine methods (Page et al. 1982). Organic C was estimated by method described by Walkley and Black (1934). Available N was determined by alkaline permanganate method, available P using $NaHCO_3$ extractant and available K using neutral ammonium acetate extractant as described in Page et al. (1982). Available metal contents were determined using DTPA extractant as described by Lindsay and Norvell (1978). Total N, P, and K in the soil samples were determined by the methods described in Page et al. (1982). For total metal analysis, soil samples were digested by method described by Jackson (1958) and analyzed with ICP-OES.

In situ soil respiration was measured for 15 days in the field during maximum tillering stage 3 days after fourth irrigation applied to the crop (Anderson 1982). Soil samples were collected during that period for studying soil biological and biochemical activity. For soil enzymes, dehydrogenase activity was measured by the method of Casida et al. (1964), alkaline phosphatase activity by the method of Eivazi and Tabatabai (1977), and urease activity by the method of Tabatabai and Bremner (1972). Soil microbial biomass C was measured by fumigation extraction on three replicates (Vance et al. 1987). The total populations of different groups of microorganisms in soil samples were enumerated by standard serial dilution technique. The agar media used were nutrient glucose agar for bacteria (Allen 1953), rose bengal agar for fungi (Martin 1950), and Kenknight's agar for actinomycetes (Allen 1953). For enumeration of coliform count, ready-made media of HIMEDIA make (HiTouch Flexiplate FL002) were used.

For analysis of P, K, Na, Ca, Mg, and heavy metals in plant, samples were digested with di-acid mixture containing concentrated HNO_3 and $HClO_4$ (in 10:1 ratio), and for analysis of N, samples were digested with concentrated H_2SO_4 (Singh et al. 1999). Phosphorus in the extract and digested samples was estimated colorimetrically, Na and K by flame photometer, Ca, Mg, and heavy metals by ICP-OES spectrophotometer.

Statistical analysis

The analysis of variance (ANOVA) technique was carried out on the data for each parameter as applicable to split-plot design (Gomez and Gomez 1984). To determine the significance of difference between means of two treatments, least significance difference (LSD) were estimated at 5% probability level, and Duncan's multiple range test was used for comparing the means. As interaction effects between the treatments were not statistically significant for most of the analyzed parameters, results of mean effects are presented separately for both main plot (water) and subplot (fertilizers) treatments. Wherever interaction effects were found statistically significant, these were discussed in the text.

Results and discussion

Changes in chemical properties of soil

Application of sewage water for 5 years did not change mean pH of surface soil significantly; though, application of mineral fertilizers alone or in combination of organic fertilizers decreased soil pH significantly over control (Table 2) at both growing (45 days after sowing) and harvesting stage of wheat crop. Single superphosphate applied in these treatments has converted into tri-calcium phosphates in the presence of free $CaCO_3$ resulting in release of protons causing reduction of soil pH (McBride 1994). Irrigation with sewage water resulted significant increase in EC in the surface soil, though not to the extent that can cause any adverse environment in the rhizosphere environment. Electrical conductivity (EC) of sewage water was found about 31–60% more than groundwater.

Untreated sewage water contained a significant amount of C (116–257 mg/L), and its application for 5 years resulted significant increase in soil organic C (SOC) in the soil profile up to 30 cm.

Table 2 Changes in some chemical and biochemical properties due to sewage irrigation and nutrient application

Treatments	Ph	EC (mS/cm)	DHA (mg TPF/g soil/h)	Alk. phosphatase activity (mg PNP/g soil/h)	Urease activity (μg NH_4–N/g soil/2 h)	Microbial biomass C (μg/g)	Basal respiration (g CO_2–C /m^2/day)
Main plot							
W_1	7.76a	0.296b	0.133b	9.44a	51.9a	37.0b	2.47b
W_2	7.74a	0.513a	0.144a	7.84a	44.9a	53.9a	3.01a
Subplot							
T_1	7.85a	0.281b	0.120b	9.72a	50.4a	50.3a	2.49b
T_2	7.69b	0.441a	0.140ab	9.21a	45.7a	57.6a	2.83ab
T_3	7.76b	0.395ab	0.126b	7.71a	46.5a	53.9a	2.67ab
T_4	7.69b	0.500a	0.165a	7.93a	50.9a	53.6a	2.97a

Column means followed by the same letter are not significantly different among themselves at 0.05 probability level

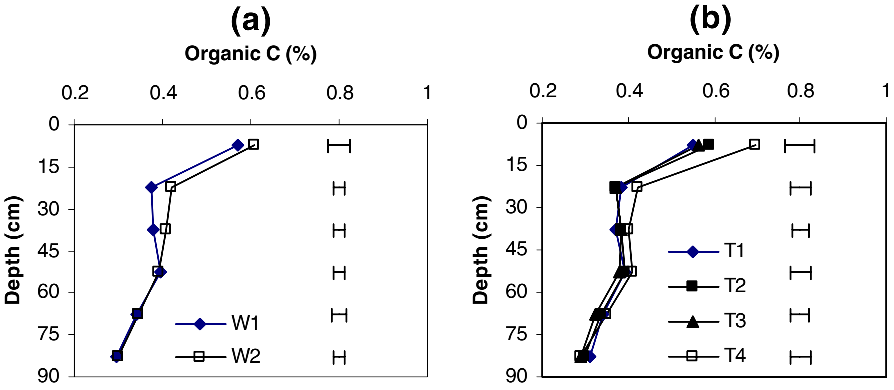

Fig. 1 Effect of **a** irrigation water quality and **b** fertilizers/manure on the organic C content in the soil profile

Magnitude of increase was higher in 15–30 cm depth compared to the topmost layer (Fig. 1a). In another experiment, it has been estimated that this soil needs more than 887.8 kg C/ha/year input in order to enhance the SOC from the equilibrium level in the current cropping system and management practices (Kundu et al. 2001). Carbon added through sewage water was, however, much less (about 72% of its input required for SOC maintenance) compared to 210% addition through manure (in T_4 treatment). Carbon added through sewage water might have percolated down through cracks and macropores and accumulated in the subsoil layers. As uppermost soil layers are subjected to frequent tilling, majority of the accumulated C are mineralized resulting little SOC build-up. On the contrary, C entered in the deeper layer are sequestered because of being less subjected to microbial attack. Manure application (equivalent to about 1,860 kg C/ha/year) in T_4 treatment caused significant SOC build-up (about 24% more) compared to no manure plots (Fig. 1b). Application of fertilizers did not result in any significant changes in SOC contents in soil layers.

Changes in biological and biochemical activity

Soil microbial biomass C during maximum tillering stage was significantly increased by about 45% due to sewage irrigation (Table 2). Application of wastewater-containing organic substances and nutrients has also been found to increase total microbial biomass (Goyal et al. 1995; Friedel et al. 2000). Sewage irrigation for 5 years has significantly increased mean fungi and actinomycetes population in the surface soil by, respectively, about 125% and 75% (Table 3). Ratios of bacteria to fungi and actinomycetes to fungi decreased considerably in both the layers due

Table 3 Changes in microbial populations in soil due to sewage irrigation and nutrient application

Treatments	Fungi population (10^3 cfu/g)	Bacterial population (10^{10} cfu/g)	Actinomycetes population (10^3 cfu/g)	Total coliform (cfu/g)
Main plot				
W_1	6.6b	15.9a	57.2b	0.7b
W_2	14.8a	23.7a	100.2a	16.0a
Subplot				
T_1	14.8ab	19.4a	72.8a	8.0a
T_2	2.2b	19.8a	64.9a	7.5a
T_3	3.9b	20.2a	101.2a	7.5a
T_4	21.9a	19.7a	76.0a	10.5a

Column means followed by the same letter are not significantly different among themselves at 0.05 probability level

to sewage irrigation for 5 years. This indicates that increase in fungal population was more than the proportional increase in bacterial and actinomycetes population, which may be due to influx of active C through untreated sewage water. Total coliform population (a group of organisms responsible for acute gastroenteritis in mammals) had significant presence in sewage-irrigated plots even after harvest of wheat crop, which was obviously due to its entry through untreated sewage water. Sewage irrigation as well as manure application resulted in significant increase in CO_2 evolution from soil surface during the 13-day period after irrigation at this physiological stage, which may be due to incorporation of C substrate and increase in metabolic activity of soil microorganisms (Table 2).

Dehydrogenase enzyme activity (DHA) was about 8.2% higher in sewage-irrigated soil compared to groundwater-irrigated soil (Table 2). Application of mineral fertilizers at highest dose (T_2) as well as manure (T_4) also increased its activity significantly. Dehydrogenase enzyme systems play significant role in oxidation of soil organic matter as they transfer H from substrate (organic compound) to acceptor. Skujin (1973) observed that DHA was highly correlated with CO_2 release. Further, Friedel et al. (2000), in their investigation on long-term sewage-irrigated area, observed that increase in DHA in sewage-irrigated soils correlated with increase in total organic C; while heavy metal build-up had an adverse effect on it. In this relatively short duration study, however, rhizodeposition of C might have played an important role in increasing DHA. Application of fertilizers, manures, as well as sewage irrigation resulted in considerable increases in aboveground biomass growth, which might have resulted in larger secretion of root exudates and consequently higher microbial metabolic activity. This may be related to the observed increases in soil DHA.

Activity of alkaline phosphatase enzyme and urease enzyme in soil during the maximum tillering stage of the crop was not significantly influenced by the application of either fertilizers or sewage irrigation (Table 2). Svensson and Pell (2001) did not find any effect in long-term inorganic P application on alkaline phosphatase enzyme, though N fertilization had an influence on it.

Changes in major nutrients content

Sewage irrigation increased available N, P, and K contents in surface soil significantly (Table 4). Available N, P, and K contents were found to be about 11.4%, 44%, and 17% more, respectively, in sewage-irrigated root zone soils compared to groundwater-irrigated soils. As sewage water was significantly contaminated with compounds of N, P, and K, its irrigation for 5 years to wheat crop added about 321 kg N, 262 kg P, and 282 kg K per ha to the land, which resulted in the observed increases in availability of these nutrients. Even after application of 150 cm of sewage irrigation during 5 years, available P content in the experimental site rose from low to high nutritional level, based on the critical level of 7.25 mg/kg as identified by Rao and Ganeshamurthy (1994). Long-term sewage application has been found to increase available P and K contents in soils of different places (Siebe 1998; Ryan et al. 2006). Extractable N, P, and K contents also increased with fertilizer applications, and maximum concentrations of these nutrients were recorded with T_4 treatment where both fertilizers and manure were applied. Siebe (1998) also observed significant increase in available P due to long-term wastewater irrigation near Mexico City.

Although sewage irrigation for 5 years added significantly higher content of P compared to fertilizer and manure, it resulted in a small increase (3.4%) in the total P content in the surface layer soil (0–15 cm), but a significant increase in the 15–30 cm (8.6%) and 30–45 cm (5.1%) soil layer (Fig. 2a). On the other hand, while there was significant increase in total P content in the surface layer (17.6%), magnitude of increase was small in subsurface layer (2.5%) due to application of single superphosphate in T_2 treatment (Fig. 2b). Phosphorus is generally immobile in soil due to its high reactivity with soil components, and hence, about 46% of the applied P was accumulated in the uppermost 15 cm layer compared to about

Table 4 Changes in major and micronutrient contents in soil due to sewage irrigation and nutrient application

Treatments	Available major nutrients (μg/g)			Total N (μg/g)	Total K (%)	DTPA extractable metals (μg/g)			
	N	P	K			Zn	Cu	Fe	Mn
Main plot									
W_1	84.2b	8.2b	242b	986a	1.13a	0.58b	1.13a	7.70b	8.35b
W_2	93.8a	11.8a	283a	1017a	1.21a	0.82a	1.21a	8.27a	9.46a
Subplot									
T_1	76.0b	5.9c	237b	956b	1.13a	0.62b	1.16a	8.03a	7.86a
T_2	95.6a	10.2b	274a	1005a	1.17a	0.65b	1.14a	7.87a	9.10a
T_3	82.4b	7.5c	246b	973ab	1.16a	0.59b	1.17a	8.22a	9.21a
T_4	102.0a	16.3a	293a	1073a	1.23a	0.92a	1.20a	7.82a	9.46a

Column means followed by the same letter are not significantly different among themselves at 0.05 probability level

22% in the next layer (15–30 cm) in the T_2 treatment. However, P applied through sewage water might have percolated down the profile through cracks, which are normally formed due to swell-shrink nature of the Vertisol. Also, sewage water contained significant proportion of organic P (17–23%), which is generally less reactive with soil component compared to inorganic phosphate ions. Therefore, average P accumulation in 15–45 cm soil layer was about 44% compared to about 12% in the topmost layer of sewage-irrigated plots. Total N and K contents in the both the layers were also increased due to sewage irrigation, though magnitudes were not statistically significant. This may be due to relatively smaller N and K addition through sewage water compared to high total N and K present in soil. Though the content of N increased significantly due to application of fertilizers and manure in T_2 and T_4 treatments, magnitude of increase in total K was statistically not significant.

Changes in trace element contents in soil

The soils of the area are generally deficient in essential micronutrients viz., B and Zn for several sensitive crops. Application of sewage significantly improved availability of Zn, Fe, and Mn as indicated by, respectively, 30%, 8.5%, and 13% increase in DTPA extractable contents of these elements (Table 4). However, no significant changes have been found in total content of these elements. High microbial population and their metabolic activity (as indicated by high microbial biomass C, dehydrogenase enzyme activity, and CO_2 evolution) indicated that partial pressure of CO_2 in the soil atmosphere might be higher in sewage-irrigated soil compared to groundwater-irrigated plots. This might have caused solubilization of $CaCO_3$ granules and consequent release of micronutrients bound by these. Available (hot water extractable) B content was found similar in both groundwater and sewage-irrigated soils.

Fig. 2 Effect of **a** irrigation water quality and **b** fertilizers/manure on the total P content in the soil profile

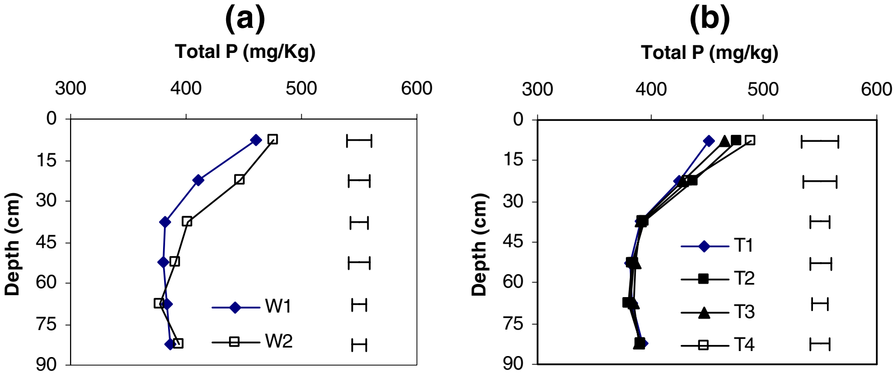

Table 5 Effect of sewage irrigation and nutrient application on leaf tissue analysis of wheat plant at panicle initiation stage

Treatments	N (%)	P (%)	K (%)	Na (μg/g)	Ca (%)	Mg (%)	Zn (μg/ g)	Cu (μg/g)	Fe (μg/g)	Mn (μg/g)
Main plot										
W_1	0.66a	0.14b	1.94a	262b	0.47a	0.18a	18.0b	8.2b	405a	72.2a
W_2	0.71a	0.19a	1.87a	352a	0.40b	0.19a	19.8a	10.5a	421a	80.2a
Subplot										
T_1	0.66a	0.16ab	1.93a	290a	0.41a	0.17a	18.2a	8.7a	415ab	74.7a
T_2	0.70a	0.17ab	1.87a	337a	0.43a	0.19a	19.8a	12.3a	402b	77.7a
T_3	0.69a	0.15b	1.90a	323a	0.44a	0.18a	18.3a	8.7a	399b	70.7a
T_4	0.69a	0.18a	1.91a	277a	0.46a	0.19a	19.3a	7.7a	434a	81.7a

Column means followed by the same letter are not significantly different among themselves at 0.05 probability level

Elemental concentration in plant tissue

At panicle initiation stage, flag leaves of wheat grown with sewage irrigation had significantly higher concentrations of N, P, Na, Zn, Cu, and Fe, but lower concentration of Ca compared to that grown with groundwater (Table 5). Increase in availability of N, P, Na, Zn, and Fe in soil may explain their increased concentration in leaf tissue in sewage-irrigated plots. Analysis of wheat grain also showed significant increase in N and Zn concentration due to sewage irrigation (Table 6). As N in grain is present mostly in the form of protein, sewage irrigation was, thus, found to increase the protein content of wheat grain by about 19%. About 42% of children in India are stunted due to low dietary intake of Zn, and increase in its concentration in wheat grain (irrigated with sewage water) might help in combating such micronutrient malnutrition.

Effect on crop yield

Average grain and straw yields of the crop were also significantly increased (31% and 43%, respectively) with sewage irrigation (Table 6). Application of fertilizers and manure improved mean grain and straw yield; maximum being recorded in plots receiving 50% RDF along with 10 Mg FYM/ha. In groundwater-irrigated plots, application of higher doses of NPK fertilizers (100% RDF in T_2) significantly increased grain yield compared to 50% RDF in T_3; however, yields in these treatments were not significantly different in sewage water-irrigated plots. Grain yield in sewage-irrigated control plot (receiving no fertilizers) was almost at par with groundwater-irrigated plots receiving 50% RDF. Thus, untreated sewage has nutrient potential equivalent to about 50% RDF and increased wheat grain yield to more than optimum level observed

Table 6 Effect of sewage irrigation and nutrient application on leaf tissue analysis of wheat plant at panicle initiation stage

Treatments	Grain yield (Mg/ha)	Straw yield (Mg/ha)	1000 seed weight (g)	Seed width (mm)	Seed N content (%)	Seed Zn content (μg/g)
Main plot						
W_1	29.77b	35.99b	45.1b	2.77b	2.20b	25.28b
W_2	38.98a	51.51a	49.1a	3.16a	2.63a	29.17a
Subplot						
T_1	23.06c	34.95b	46.2a	2.87b	2.27a	28.06a
T_2	38.89a	47.60a	47.2a	3.02a	2.52a	26.94a
T_3	33.14b	42.41ab	47.9a	3.01a	2.53a	28.61a
T_4	42.41a	50.04a	47.1a	2.95ab	2.33a	25.28a

Column means followed by the same letter are not significantly different among themselves at 0.05 probability level

(3.2 Mg/ha) in this area irrigated with groundwater. Nutrients supplied through sewage were at the level of 67% N, 108% P, and 117% K of the 100% RDF. Thus, N might be the limiting nutrient in sewage-irrigated plots when compared with recommended dose of fertilizers for this crop. Sewage water samples in the present study contained a lower amount of N compared to those reported from other places. Test weight as well as width of grain of wheat crop grown with sewage water were 9% and 14% more compared to those grown with groundwater irrigation (Table 6). This indicates that seeds of wheat crop grown with sewage water were heavier and bold compared to that grown with groundwater.

Conclusions

Sewage irrigation of about 150 cm over a period of 5 years did not leave any adverse effect on soil chemical parameters, except slight increase in salinity. Carbon accumulated below plough layer in sewage-irrigated soil is less prone to microbial mineralization due to less aeration and, therefore, is sequestered for longer time. Increase in availability of P in the surface layer as well as its accumulation in subsoil layer indicates that P fertilization can be omitted in the sewage-irrigated area at frequent intervals of cropping cycle. Increases in DTPA extractable Zn content in soil due to sewage irrigation were also reflected in its concentration in leaf tissue and grain. Increases in soil microbiological activity might also be responsible for transformation of nutrients like P and Zn in this deficient soil. Nutrients supplied through sewage water were not able to raise the productivity of wheat to the level that obtained through fertilizers at the recommended level which indicated that additional nutrients particularly N through fertilizer are required to obtain higher productivity of wheat under sewage farming. Bold seed size coupled with higher protein and Zn content in wheat grains showed an improved seed quality due to sewage irrigation.

Overall results show that short duration (5 years) of municipal sewage water irrigation did not have any harmful effect on soil quality as well as crop productivity except for slight build-up in coliform population; rather, it proved beneficial in improving soil fertility, wheat productivity, and produce quality. However, the long-term effect of sewage farming on soil quality parameters needs to be observed.

References

Allen, O. N. (1953). *Experiments in soil bacteriology.* Minneapolis, USA: Burgess.

Anderson, J. P. E. (1982). Soil respiration. In A. L. Page, R. H. Miller, & D. R. Keeney (Eds.), *Methods of soil analysis, part 2. Chemical and microbiological properties. Agronomy Monograph* (Vol. 9, pp. 837–871). Madison, Wisconsin, USA: ASA-SSSA.

Bhise, P. M., Challa, O., & Venugopalan, M. V. (2007). Effect of waste water irrigation on soil properties under different land use systems. *Journal of the Indian Society of Soil Science*, *55*, 254–258.

Casida, L. E., Jr, Kelvin, D. A., & Santoro, T. (1964). Soil dehydrogenase activity. *Soil Science, 98*, 371–376. doi:10.1097/00010694-196412000-00004.

Eivazi, F., & Tabatabai, M. A. (1977). Phosphatases in soils. *Soil Biology & Biochemistry, 9*, 167–172. doi:10.1016/0038-0717(77)90070-0.

Friedel, J. K., Langer, T., Siebe, C., & Stahr, K. (2000). Effects of long-term waste water irrigation on soil organic matter, soil microbial biomass and its activities in central Mexico. *Biology and Fertility of Soils, 31*, 414–421. doi:10.1007/s003749900188.

Ghafoor, A., Qadir, M., Sadiq, M., Murtaza, G., & Brar, M. S. (2004). Lead, copper, zinc and iron concentrations in soils and vegetables irrigated with city effluent on urban agricultural lands. *Journal of the Indian Society of Soil Science, 52*, 114–117.

Gomez, K. A., & Gomez, A. A. (1984). *Statistical procedures of agricultural research—an IRRI book.* New York, USA: Wiley.

Goyal, S., Chander, K., & Kapoor, K. K. (1995). Effect of distillery wastewater application on soil microbiological properties and plant growth. *Environment and Ecology, 13*, 89–93.

Greenberg, A. E., Clesceri, L. S., Eaton, A. D., & Franson, M. A. H. (1992). *Standard methods for the examination of water and waste water* (18th ed.). Washington, D.C. 20005: American Public Health Association.

IWMI (2002). *Reuse of wastewater for agriculture. The hyderabad declaration on wastewater use in agriculture.* International Water Management Institute, India. http://www.iwmi.cgiar.org/health/wastew/hyderabad_declaration.htm.

Idelovitch, E., & Michael, M. (1984). A new approach to an old method of wastewater reuses. *Journal - Water Pollution Control Federation, 56*, 930.

Jackson, M. L. (1958). *Soil chemical analysis*. Englewood Cliffs, N.J.: Prentice-Hall.

Kakar, R. G., Yasinzai, M., Salarzai, A. U., Oad, F. C., & Siddiqui, M. H. (2006). Irrigation with sewage water: Assessment of water quality, nutrients and heavy metal distribution. *Asian Journal of Plant Science, 5*, 438–440.

Kundu, S., Singh Muneshwar, Saha, J. K., Biswas, A. K., Tripathi, A. K., & Acharya, C. L. (2001). Relationship between C addition and storage in a Vertisols under soybean-wheat cropping system in sub-tropical central India. *Journal of Plant Nutrition and Soil Science, 164*, 483–486. doi:10.1002/1522-2624(200110)164:5<483::AID-JPLN483>3.0.CO;2-Y.

Lindsay, W. L., & Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal, 42*, 421–428.

Martin, J. P. (1950). Use of acid, rose Bengal and streptomycin in the plate method of estimating soil fungi. *Soil Science, 69*, 215–233.

McBride, M. B. (1994). *Environmental chemistry of soils*. 200 Madison Avenue, New York 10016: Oxford University Press.

Page, A. L., Miller, R. H., & Keeney, D. R. (1982). *Methods of soil analysis, part 2. Chemical and microbiological properties. Agronomy Monograph* (Vol. 9). Madison, Wisconsin, USA: ASA-SSSA.

Rao, A. S., & Ganeshamurthy, A. N. (1994). Soybean responses to applied phosphorus and sulfur in Vertic Ustochrept in relation to available phosphorus and sulfur. *Journal of the Indian Society of Soil Science, 42*, 606–610.

Ryan, J., Masri, S., & Qadir, M. (2006). Nutrient monitoring of sewage water irrigation: Impacts for soil quality and crop nutrition. *Communications in Soil Science and Plant Analysis, 37*, 2513–2521. doi:10.1080/00103620600822960.

Siebe, C. (1998). Nutrient inputs to soils and their uptake by alfalfa through long-term irrigation with untreated sewage effluent in Mexico. *Soil Use and Management, 14*, 119–122. doi:10.1111/j.1475-2743.1998.tb00628.x.

Singh, D., Chhonkar, P. K., & Pandey, R. N. (1999). *Soil plant water analysis: A methods manual*. New Delhi: Indian Agricultural Research Institute.

Skujin, J. (1973). Dehydrogenase: An indicator of biological activities in arid soils. *Bulletin on Ecological Research Communication NFR, 17*, 235–241.

Smith, R. G., & Schroeder, E. D. (1985). Field studies to the overland flow process for the treatment of raw and primary treated municipal wastewater. *Journal - Water Pollution Control Federation, 56*, 785.

Svensson, K., & Pell, M. (2001). Soil microbial tests for discriminating between different cropping systems and fertilizer regimes. *Biology and Fertility of Soils, 33*, 91–99. doi:10.1007/s003740000292.

Tabatabai, M. A., & Bremner, J. M. (1972). Assay of urease activity in soils. *Soil Biology & Biochemistry*, *4*, 479–487. doi:10.1016/0038-0717(72)90064-8.

Vance, E. D., Brooks, P. C., & Jenkinson, D. S. (1987). An extraction method for measuring soil microbial biomass C. *Soil Biology & Biochemistry, 19*, 703–707. doi:10.1016/0038-0717(87)90052-6.

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determination of soil organic matter and proposed modification of chromic acid titration method. *Soil Science, 37*, 29–38. doi:10.1097/00010694-193401000-00003.