Effect of Short-term Sewage Irrigation on Chemical Build Up in Soils and Vegetables

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ABSTRACT

Reuse of sewage as irrigation water is one of the best options to reduce the stress on limited fresh water available today and to meet the nutrient requirement of crops. But the use of raw or untreated sewage can cause accumulation of heavy metals in the soil and hence may cause phyto-toxicity. A mini-lysimeter study based on Completely Randomized Design experiment was conducted to evaluate the effect of different concentrations of sewage irrigation *viz.* sewage water as such, well water as such and sewage water as such: well water as such, 1:1 on the physio-chemical properties of soils *viz.* sandy loam and sandy clay loam soils and chemical build up in vegetable crops *viz.* Indian spinach (*Beta vulgaris* var. bengalensis), carrot (*Daucus carota* L.) and cauliflower (*Brassica oleracea* L.). All these treatments made 18 treatment combinations which were replicated thrice. Application of sewage water as such or in its dilutions improved the physico-chemical properties and nutrient status of the soil but resulted higher per cent build up of metallic cations in soil, particularly Zinc, Lead and Nickel in sandy clay loam soil and Copper and Cadmium in sandy loam soil. Indian spinach irrigated with sewage water as such or its dilution increased organic carbon content of the soils while, in cauliflower and carrot calcium carbonate content was decreased. Metallic cations content in the leaves and roots of the crops recorded an increase when crops were irrigated with sewage water as such or in its dilution. However, the metallic cations content in the leaves and roots were quite below the maximum permissible limits suggested. The per cent build up of metallic cations in soils and vegetables due to sewage irrigation in 100 days showed that there might be accumulation of heavy metals in soil and cause phyto-toxicity if such sewage water is used continuously for irrigation. This clearly indicates a need for the treatment of sewage water before it is being diverted for irrigation.

Keywords: Metallic cations, sewage water, irrigation, metallic cations contamination, mini-lysimeter, phyto-toxicity

1. INTRODUCTION

Untreated wastewater from rural and suburban communities or failed on-site wastewater treatment systems is one of the main factors that result in eutrophication of rivers and lakes (Lei et al. 2006). For this reason, land application of sewage and sludge has increased as a means of safe disposal and recycling of such materials (Petruzzelli, 1989). Depending on origin, the effluents are laden with appreciable concentration of organic and inorganic nutrients (Mitra and Gupta, 1999; Berrow and Webber, 1972) and can meet the nutrient requirement of the plants if used for irrigation. According to the report of USEPA (1992) effluents are reused for irrigation purposes in many countries around the world on all the populated continents. Metabolic activity of soil microorganisms have also been reported to increase when sewage effluent is used for irrigation (Meli et al., 2002; Ramirez-Fuentes et al., 2002). The other important aspect is that it contributes in reducing the stress on the amount of water that needs to be extracted from environmental water sources (USEPA, 1992; Gregory, 2000) for various purposes like for agriculture.

Raw or untreated and/or injudicious application of effluents in soil may give rise to accumulation of heavy metals in the top soil (Williams et al., 1980) and hence in tissues of plant grown on them (Mays et al., 1973; Day et al., 1979). Paliwal et al. (1998) irrigated *H. binata* seedlings with different concentration (0, 25, 50, 75 and 100%) of sewage for 75 days resulting metals in soil in the order: Nitrogen (N)> Calcium (Ca)> Magnesium (Mg)> Potassium (K)> Sodium (Na)> Phosphorus (P)> Manganese (Mn)> Zinc (Zn)> Lead (Pb)> Copper (Cu) and increased concentration of N and P in the plant components with increased concentration of sewage water. Similarly beyond seedling growth, the short term effect of sewage water irrigation on soil and crop growth period has not been addressed much so far. This study therefore has the objectives to i) evaluate the short-term effect of different dilutions of sewage water on physio-chemical properties of sandy loam and sandy clay loam soils and ii) assess the chemical build up in Indian spinach, cauliflower and carrot grown on mini-lysimeters.

2. MATERIAL AND METHODS

2.1 Description of the Area under Study

The experiment was conducted in the greenhouse of Department of Agricultural Chemistry and Soil Science, Rajasthan College of Agriculture, Udaipur using mini-lysimeters. The Udaipur is situated at the step foot of Aravali hills at 24035' N latitude and 73042' E longitude with an altitude of 582.17 m above mean sea level. This region falls under Agro-climatic Zone IV-a, "Sub-humid Southern Plain and Aravali Hills" of Rajasthan. It has a typical sub-humid climatic conditions characterized by mild winters and moderate summers with higher relative humidity during the months of July to September. The average rainfall of Udaipur is 637 mm, most of which is received during the last week of June to September contributed by south-west monsoon. Winter showers occur occasionally.

2.2 Experimental Set Up

The mini-lysimeters (65x22 cm.) were filled separately with two texturally different soils, sandy loam (SL) and sandy clay loam (SCL) soils belonging to Haplustepts of Sub-humid Southern Plains of Rajasthan, Udaipur, India. Three vegetable crops *viz*., cauliflower, carrot and Indian spinach were grown from 13 October 2003 to 23 January 2004. Three sewage dilutions including well water as such, sewage water as such, and sewage and water in equal proportions (1:1). The sewage water was collected from the sewage drains of Udaipur City. Three replications of 18 treatments combinations (2 soils X 3 vegetable X 3 sewage dilutions) were laid out on Completely Randomized Design.

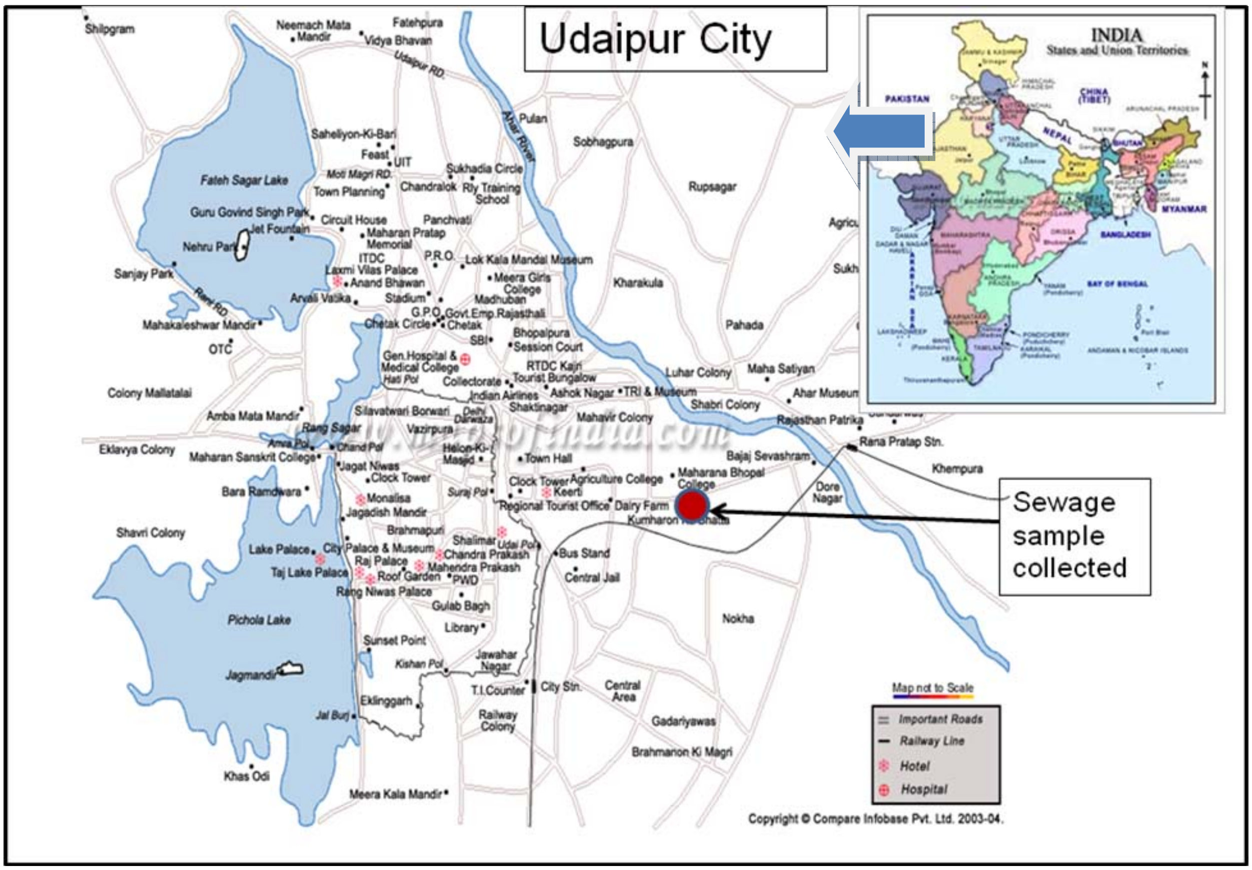

Figure 1. Map showing the study location

The well and sewage water used for preparing various dilutions have total suspended solids (TSS) and pH within safe range for irrigation (ISI, 1982; Ayers and Westcot, 1985) (Table 1). The electrical conductivity (EC) was slight to moderately saline. The metallic cations content were below the maximum permissible limits as prescribed by Pratt (1972). However, looking at the level of Na and adjusted sodium absorption ratio (adj. SAR) in the irrigation waters, may pose a severe problem of specific ion toxicity and permeability (Ayers and Westcot, 1976).

Table 1. Characteristics of well and sewage water

Characteristics	Unit	Well water	Sewage water
TSS	mg L^{-1}	11	167.16
pH	-	8.18	7.82
EC	dSm^{-1}	1.09	2.18
Na	me L^{-1}	11.91	15.89
Adj. SAR	-	10.87	11.69

The soil samples were drawn prior to experimentation and at harvest of vegetable crops and analyzed for physio-chemical properties following standard methods of analysis (Richards, 1954; Singh, 1989 and Piper, 1950). The DTPA (Diethylenetriamine pentaacetic acid) extractable metallic cations Zn, Cu, Fe (iron), Mn, Pb, Cd (Cadmium) and Ni (Nickel) were analyzed following the method suggested by Lindsay and Norvell (1978). The leaves and root samples of the vegetable crops grown were analyzed for metallic cations in the extract using standard methods (Jackson, 1967) and Atomic Absorption Spectrophotometer (AAS). The sandy loam and sandy clay loam soils used were non-saline, mildly alkaline and calcareous in nature (Table 2). The status of available N and P was medium, while K was high in both the soils. The DTPA extractable Zn, Cu and Mn were high, while Fe was marginal in both the soils.

Table 2. Physico-chemical properties of soil prior to experimentation

Parameter	Unit	Sandy loam	Sandy clay loam
EC	dSm^{-1}	0.47	0.84
pH	-	8.17	8.28
$CaCO_3$	g kg^{-1}	40	32.07
Available N	Kg ha^{-1}	235	287
Available P	Kg ha^{-1}	18	23
Available K	Kg ha^{-1}	344	370
DTPA extractable metallic cations			
Zn	mg kg^{-1}	1.36	2.11
Cu	mg kg^{-1}	0.49	0.62
Mn	mg kg^{-1}	3.19	5.1
Fe	mg kg^{-1}	2.78	3.16

The analyzed soil and plant samples were subjected to statistical analysis and their significance were judged using analysis of variance technique as suggested by Fisher (1950). The test of significance (F-test) was used for estimation of the treatment differences as described by Cochran and Cox (1959). The percent build of metallic cations after use of sewage water as such in the soils and vegetable crops was based on simple arithmetic computation with reference to the control (use of well water as such). The percent build up of metallic cations in soils was computed irrespective of the crops grown on them by taking the mean of the per cent build up of the cations under each soil textures and vice versa for the per cent build up of metallic cations in the leaves and roots of the crops irrespective of the soil textures.

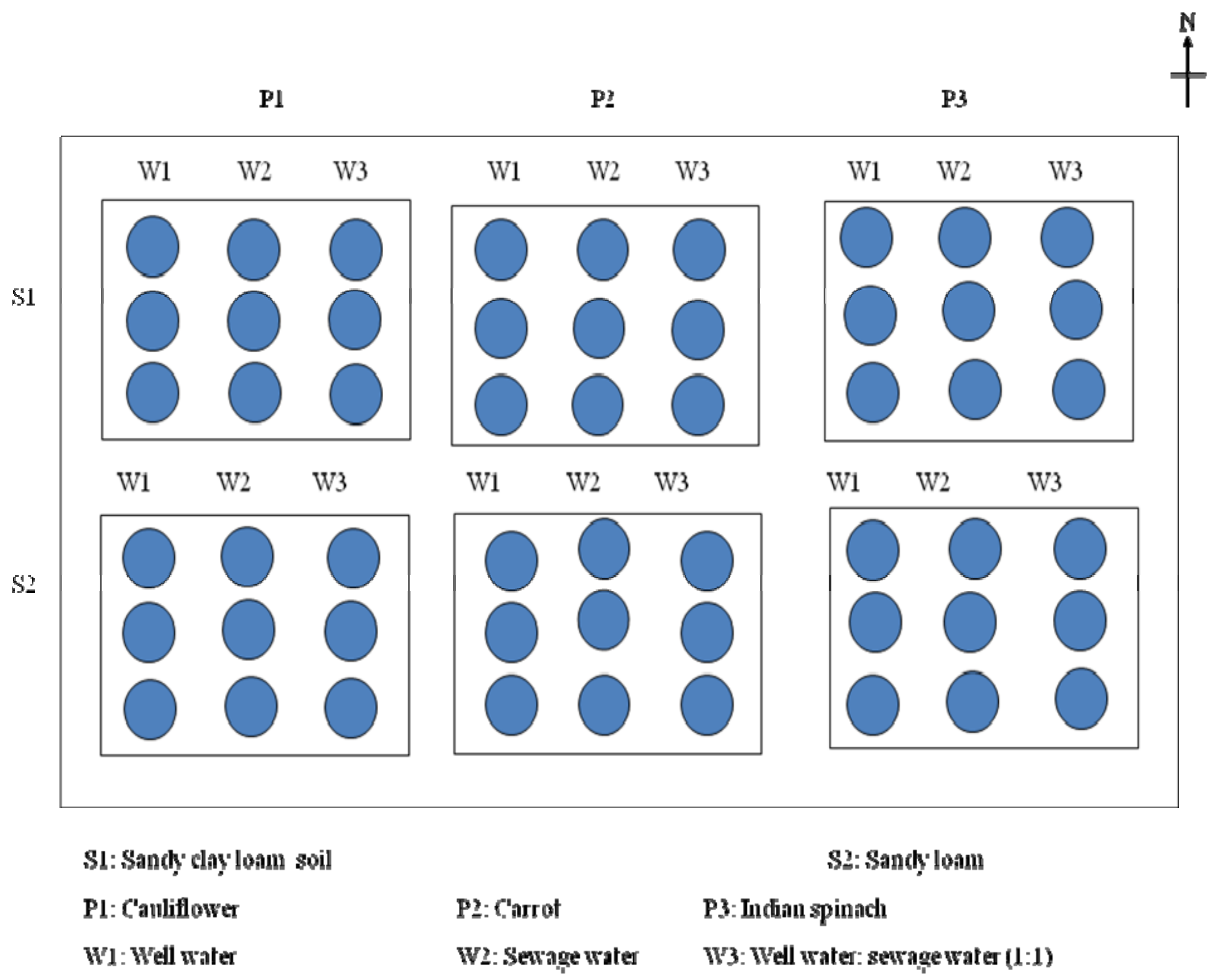

Figure 2. Layout of completely randomized design with 3 treatments and 3 replications

3. RESULTS AND DISCUSSION

3.1 Effect on Soil Properties

3.1.1 Physical Properties

High bulk density and hydraulic conductivity in sandy loam soil was due to its coarser texture as compared to sandy clay loam, while reverse was true for porosity and water holding capacity (WHC) (Table 3). An increase in porosity and WHC of soils was observed when soils were irrigated with sewage water as such or in its dilution while, decrease in the bulk density indicated an enrichment of fine fractions i.e. silt and clay apart from the organic fraction. However, the hydraulic conductivity of the soils significantly decreased which is attributed to the clogging of larger pores by the suspended solids settled therein in the soils irrigated with sewage water (Shende, 1984; Tarchitzky et al. 1999).

Table 3. Effect of sewage application and soil texture on physical properties of the soils

Treatment	Bulk density (Mg m^{-3})	Porosity (%)	Hydraulic conductivity (cm hr^{-1})	WHC (%)
Soil texture				
Sandy loam	1.52 (1.58)	42.86 (39.66)	1.78 (2.11)	40.50 (37.61)
Sandy clay loam	1.44 (1.46)	44.85 (41.68)	1.23 (1.26)	44.74 (40.12)
SEm±	0.007	0.385	0.013	0.286
CD (P=0.05)	0.021	1.103	0.036	0.819
Sewage dilution (well: sewage water)				
Well water as such, 1:0	1.52	40.7	1.67	39.98
Sewage water as such, 0:1	1.46	46.86	1.29	45.73
Well: sewage water, 1:1	1.48	44	1.57	42.15
SEm±	0.009	0.471	0.016	0.35
CD (P=0.05)	0.026	1.351	0.044	1.003

Note: Figures in parenthesis are the initial value prior to experimentation

3.1.2 Chemical Properties

The effect of soil texture, sewage dilutions and vegetable crops on some of the chemical properties of the soils was analyzed (Table 4). The decrease in pH was more in the sandy loam soil as compared to sandy clay loam soil, and this could be due to lower buffering capacity of sandy loam soil as compared to sandy clay loam soil registering a change in pH (Brady and Weil, 2002). A decrease in pH of the soil with the use of sewage dilutions for irrigation might be due to lower pH of sewage water (7.20 to 7.88) being used for irrigation. Significantly highest value of EC was observed for sandy clay loam soil irrigated with sewage water as such as compared to rest of the treatment combinations indicating a higher build-up of salts in moderately fine textured soil. This could be ascribed to its high salt content with a mean value of 2.18 dS m^{-1} as against 1.09 dS m^{-1} of well water and hence contributing more dissolved salts in the soil. Similar results of pH were reported by Palaniswami and Sree Ramulu (1994), and Sharma and Totawat (2002) and of EC were reported by Sree Ramulu (1994), Zalawadia et al. (1997). Further, the soils on which carrot and Indian spinach grown soils recorded a little higher EC than cauliflower grown soils.

Table 4. Effect of soil texture, sewage dilutions and vegetable crops on chemical properties of the soils

Treatment	pH_2	EC_2 (dSm^{-1})	OC (g kg^{-1})	$CaCO_3$ (g kg^{-1})	Available nutrient status (kg ha^{-1})		
					N	P	K
Soil texture							
Sandy loam	7.64 (8.12)	0.81 (0.47)	6.92 (5.22)	37.04 (40.08)	272 (235)	23 (18)	341 (343)
Sandy clay loam	7.78 (8.23)	1.37 (0.84)	10.67 (7.75)	29.73 (32.70)	332 (287)	25 (23)	377 (370)
SEm±	0.026	0.1	0.041	0.22	1.63	0.16	2.61
CD (P=0.05)	0.07	0.02	0.11	0.64	4.69	0.46	7.49
Sewage dilution (well: sewage water)							
Well water as such, 1:0	8.19	0.73	6.61	37.02	262	20.82	347
Sewage water as such, 0:1	7.27	1.42	11.32	27.85	346	28.09	372
Well: sewage water, 1:1	7.68	1.12	8.46	35.29	298	25.76	358

SEm±	0.032	0.012	0.051	0.277	2	0.2	3.2
CD (P=0.05)	0.09	0.03	0.14	0.79	5.74	0.56	9.18
Vegetable crops							
Cauliflower	7.76	1.04	8.71	32.6	302	25.24	367
Carrot	7.71	1.13	8.66	33.28	309	24.99	360
Indian spinach	7.67	1.1	9.02	34.28	296	24.44	350
SEm±	0.03	0.01	0.05	0.27	2	0.2	3.2
CD (P=0.05)	NS	0.03	0.14	0.79	5.74	0.56	9.18

Note: Figures in parenthesis are the initial value prior to experimentation

Available N, P and K status, OC and metallic cation content values were significantly higher in sandy clay loam than in sandy loam soils. It was further enhanced with sewage water irrigation as such or in its dilution indicating improvement in the fertility status of the soils except build up of metallic cations in the soil. The increase in N, P and K content of soil with prolonged irrigation was also reported by (Waly, 1987). Sandy loam soil contained a higher value of $CaCO_3$ content which decreased on application of sewage water as such or in its dilution. The reduction in $CaCO_3$ was further enhanced when carrot and cauliflower were raised on such soil which is attributed to the high Ca requirement of these crops (Thompson and Kelly, 1983; Mitra et al., 1990).

3.1.3 Metallic Cations Build Up

The Figure 3a and 3b shows the per cent build up of metallic cations in the soils when vegetable crops were irrigated with sewage water as such with reference to the control. Considering the mean values of the per cent build up of metallic cations irrespective of the crops grown on them, a higher per cent build up of Zn (215%) and Ni (3289%) was recorded for sandy clay loam soil while, the build up of Pb (15067%) and Cd (9391%) was comparatively higher in sandy loam soil.

Similarly, irrespective of the textural class of the soils build up of Zn (234%), Cu (909%), Fe (71%) and Mn (123%) was relatively higher in soil where carrot was grown, while build up of Pb (24653%) was higher in soil where cauliflower was grown and Cd (9215%) and Ni (4210%) was higher in soil where Indian spinach was grown. These may be ascribed to differential removal of cations from the soil by the vegetable crops under study (Brady and Weil, 2002). The increase in DTPA extractable metallic cations was also reported by Gupta *et al*, 1998.

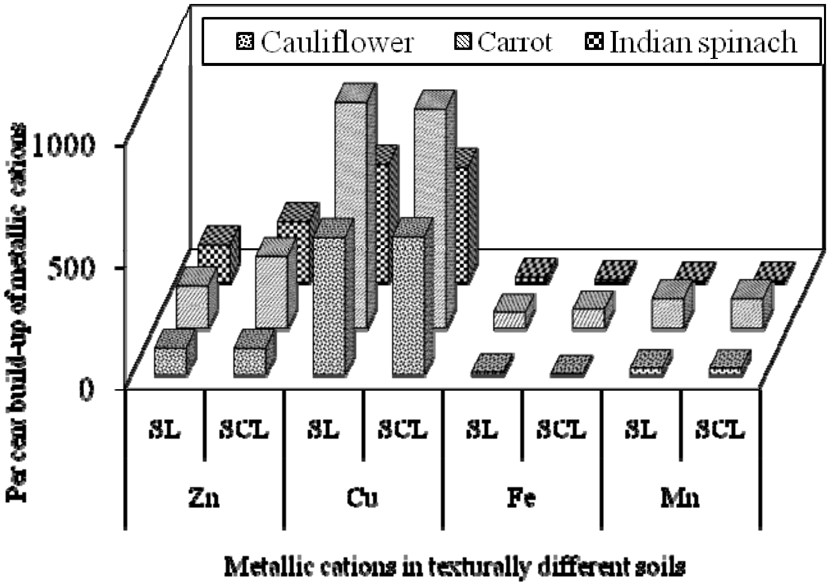

Figure 3a. Per cent increase in metallic cations in soils when irrigated with sewage water as such against well water

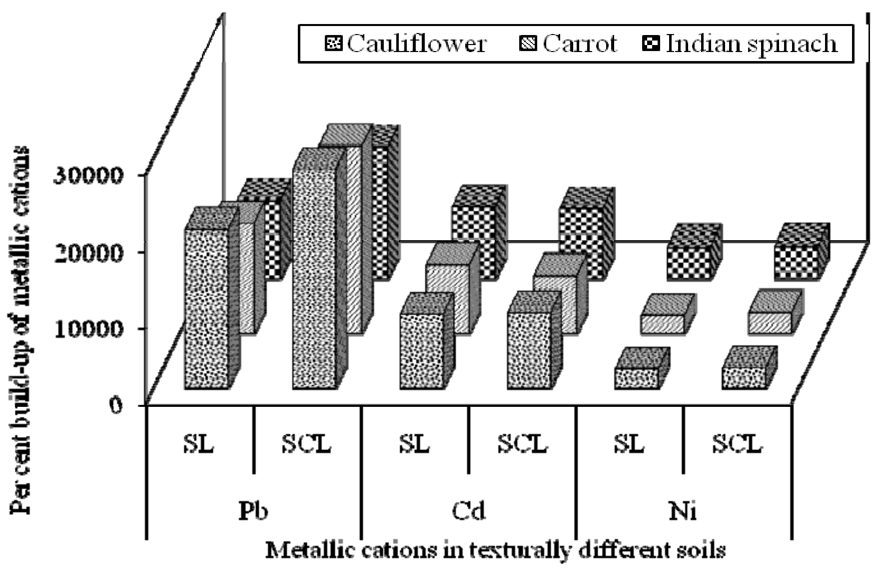

Figure 3b. Per cent increase in metallic cations in soils when irrigated with sewage water against well water

3.2 Effect on Plant Composition
3.2.1 Metallic Cations Build Up in Leaves and Roots

The per cent build up of metallic cations in the leaves and roots of vegetable crops when irrigated with sewage water as such with reference to the control is given in Figure 4a and 4b. Considering the mean values of the per cent build up of metallic cations in the leaves of crops irrespective of the type of crop grown, comparatively higher build up of Zn (232%), Cu (294%), Fe (151%), Mn (53%) and Ni (416%) was observed when crops were grown on sandy loam soil. While, higher build up of Pb (1.14 mg kg^{-1}) and Cd (0.04 mg kg^{-1}) was observed when grown on sandy clay loam soil. However the build up of metallic cations in both the textured soils did not vary significantly. Irrespective of the textural class of the soil, per cent build up of Fe (179%) and Ni (553%) was higher in the leaves of cauliflower, while Zn (295%), Cu (360%) and Mn (69%) was higher in the leaves of Indian spinach. Further cauliflower registered a little higher build up of Pb (1.45 mg kg^{-1}) and Cd (0.043 mg kg^{-1}) in their leaves which was closely followed by in the leaves of Indian spinach (Pb, 1.19 mg kg^{-1} and Cd 0.034 mg kg^{-1}), as compared to carrot which registered the lowest value of these cations (Pb, 0.18 mg kg^{-1} and Cd 0.02 mg kg^{-1}).

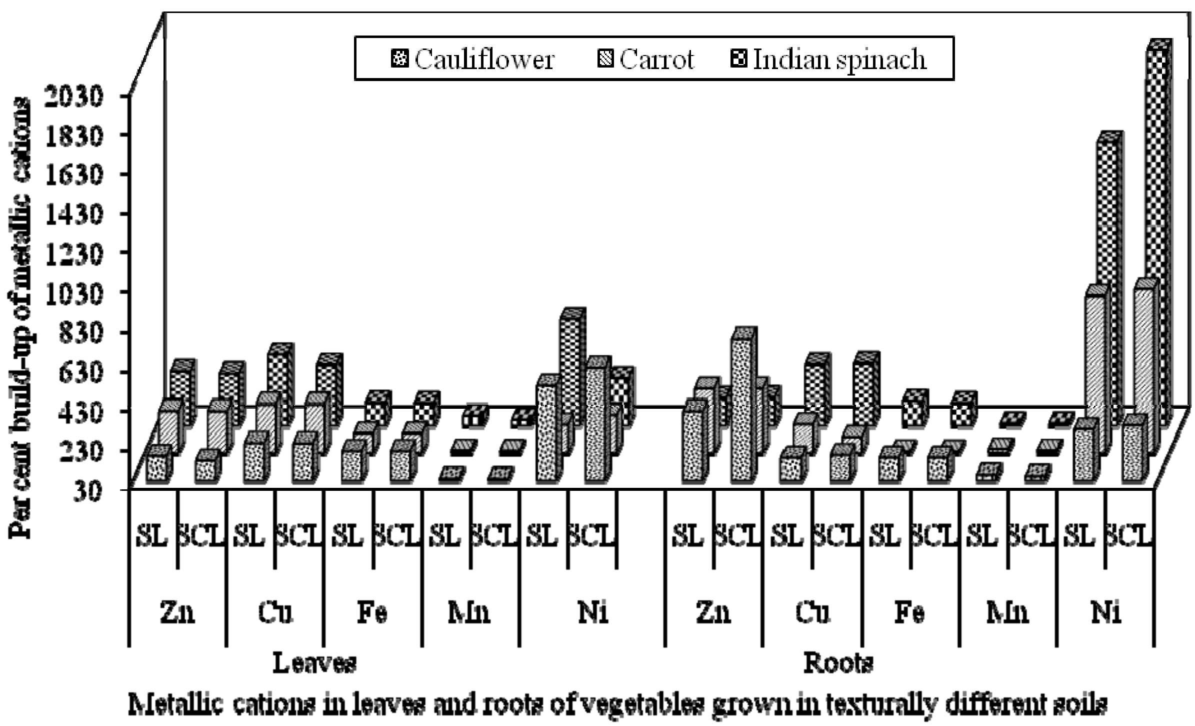

Figure 4a. Per cent increase in metallic cations when irrigated with sewage water as such as against well water

Similar to the per cent build up of metallic cations in leaves, comparatively higher build up of Zn (423%) and Ni (1033%) was recorded in the roots of crop grown on sandy clay loam soil, while build up of Cu (218%), Fe (111%) and Mn (49%) was higher when grown on sandy loam soil. Build up of Pb (0.37 mg kg^{-1}) and Cd (0.03 mg kg^{-1}) was found higher in sandy clay loam soil. However build up of the metallic cations in both the textured soils were close to each other.

Irrespective of the textural class of the soils, per cent build up of Zn (563%) and Mn (55%) was higher in the roots of cauliflower, while build up of Ni (841%) was higher in the roots of carrot and Cu (339%) was higher in the roots of Indian spinach. Further, higher build up of Pb was in the roots of cauliflower (0.64 mg kg^{-1}) and Cd in the roots of carrot (0.04 mg kg^{-1}) compared to other crops irrespective of the soil textures.

The variations in the per cent build up of metallic cations in the soils and vegetable crops may be attributed to a greater variation in the initial values of the metallic cations in the soil prior to experimentation and preferential absorbance of a particular cation by different vegetable crops under study (Sharma and Totawat, 2002, Park *et al*. 2003). Even if the concentration of heavy

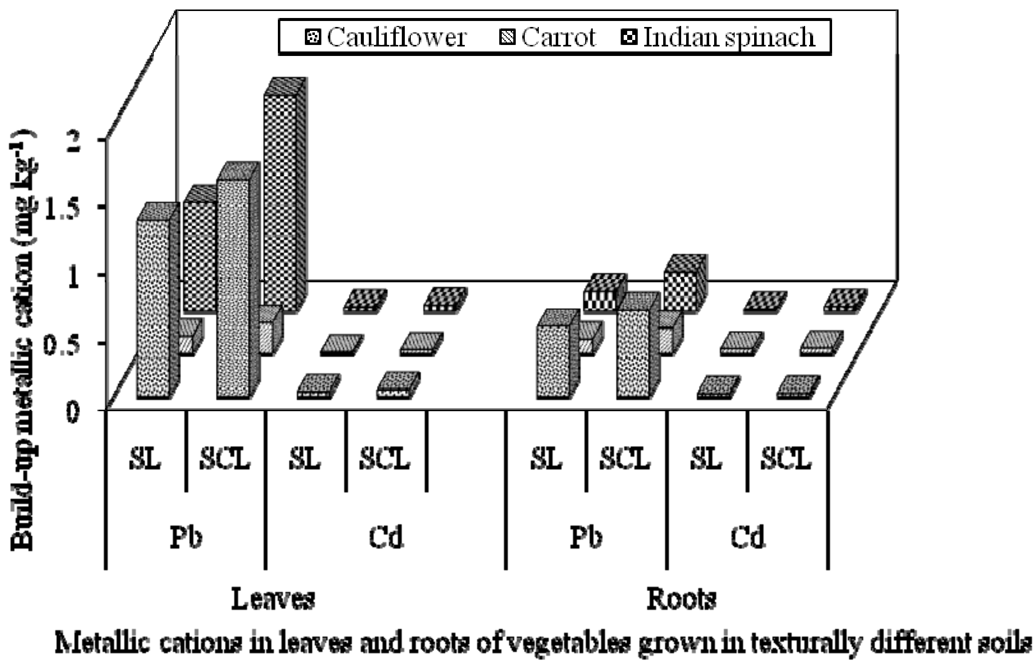

Figure 4b. Metallic cations build-up in leaves and roots of vegetable crops when irrigated with sewage water as such as against well water

metal in sewage effluents is low, the extent of build-up of metals in sewage/waste water-irrigated soils often depends on the period of its application (Bansal et al., 1992; Palaniswami and Sree Ramulu, 1994; Rattan *et al*., 2002). In spite of higher per cent build up of metallic cations in the vegetable crops, they were all within the safe limit prescribed by WHO, 1996.

4. CONCLUSIONS

Generally speaking, sewage water irrigation improved physico-chemical properties and fertility status of both soils. The metallic cations contamination of vegetable crops was observed to be below the maximum permissible limit. However, several folds build up of metallic cations in soils, leaves and roots of vegetable crops under study indicated that there might be an increase in metallic cations contamination beyond maximum permissible limit if such sewage water is continuously used for irrigation on long term. Thus timely monitoring of sewage water, soil and crops is essential to maintain soil quality for consumption of safe foods grown on them. Establishment of at least a primary sewage treatment plant is suggested where raw sewage is being diverted for irrigation.

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