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Effects of Treated Municipal Wastewater and Sea Water Irrigation on Soil and Plant Characteristics

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ABSTRACT: The increasing need for water in the arid areas of the world has resulted in the emergence of wastewater application for agriculture and landscape. Using treated wastewater in agricultural irrigation can provide more adequate supply of high quality water for human consumption, but their heavy metal applications effect must be regulated to ensure no physiological problems for both the plant and its consumer. The objective of the present research was to study the effects of treated wastewater on soil chemical properties and plant growth characteristics as well as accumulation of heavy metals in plant tissues. This research was conducted at Qatar university greenhouse in the growing season of 2007. Treated wastewater was obtained from Abu Nakhala pond in Doha City, Qatar. The soil was a mixture of sand and clay with ratio of (1:1). Two crop plants were used in this study; grain sorghum (*Sorghum bicolor* L.) and Sunflower (*Helianthus annuus* L). Plants were irrigated with four different mixtures of wastewater and sea water (1:0, 1:1, 3:1, and 0:1) in addition to potable water as a control. The accumulation of salts and heavy metals in the soil as well as concentration of the nutrients and heavy metal accumulation in the plant tissues were determined at the end of the experiment. Cr, Mn and Zn showed significant differences between soil irrigated with portable tap water and other irrigation treatments. On the other hand, Al, Fe, Ni, Co, Cu, As, Cd and Pb did not show significant differences among the irrigation water treatments. Sorghum soils have significantly less concentration of Co, Cu and As compared to that of Sunflower soils. Sorghum was found to accumulate significantly higher concentration of Mn and Zn (72.47 and 92.00 mg/L, respectively) than that of Sunflower. On the other hand, Sunflower has significantly higher concentration of Cr compared to that of Sorghum.

Key words: Wastewater, Irrigation, Soil, Plant, Heavy metals, Environment

IINTRODUCTION

In developing countries, especially in arid and semi-arid areas such as Gulf countries, wastewater is very important. Municipal wastewater could be defined as water that has been used in homes and businesses that is not for reuse unless treated by a wastewater facility. Wastewater should be treated to reduce pathogenic micro-organisms to acceptable levels, to ensure there is no threat to human health. Qatar faces a great challenge to meet water demands and manage its limited hydrological resources. Wastewater reuse should be an alternative water resource especially for the agricultural irrigation. Using treated wastewater in agricultural irrigation can provide more adequate supply of high quality water for human consumption, but their heavy metal applications effect must be regulated to ensure no physiological problems for both the plant and its consumer.

Treated wastewater has been used for crop irrigation in the developing countries (Kansel and Singh, 1983; Abdel-Reheem *et al.*, 1986; Bahri, 1988). Municipal wastewater generally contains high concentrations of suspended and dissolved solids (chloride, sodium, boron and heavy metals) and little of any added salt is removed during

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conventional (secondary and tertiary) treatments.Hydrological soil properties are especially sensitive to wastewater compounds. Indeed, numerous studies (Pescod, 1992; Bresler, 1981; Tarchitzky *et al.,* 1984; Vinten *et al.*, 1991) have highlighted hydraulic conductivity reduction in wastewater irrigated soil, ascribing it to a partial biological clogging of soil pores due to increased biomass and suspended solids. However accurate effluent management strategies, including wastewater treatment level, crops grown, irrigation methods, and cultivation and harvesting practices, can reduce contamination of irrigated vegetables and soil (Phene *et al.,* 1992; Ayars *et al.,* 1999; Pereira *et al.,* 2002; Assadian *et al.,* 1999).

There is potential for inorganic nutrients present in recycled water to be used as a fertilizer source. Soil microorganisms have been observed to increase metabolic activity when sewage effluent is used for irrigation (Meli *et al.,* 2002; Ramirez-Fuentes *et al.,* 2002). On the other hand, irrigation with wastewater raises sanitary problems (risk of viral and bacterial infection both for farmers and crops) and problems of agronomic nature, due to the presence of toxic substances. To avoid health hazards and damage to the natural environment wastewater must be treated before it can be used for agricultural and landscape irrigation (Pereira *et al.,* 2002). The effluent for reuse must comply with reuse standards to minimize environmental and health risks (WHO, 1989).

However, the need to preserve existing water resources has led to a re-evaluation of this practice focusing on more environmentally sound methods.Various studies have shown that land application of treated municipal wastewater as water and/or nutrient source for agricultural crop production can represent a sustainable alternative (Day and Tucker, 1959; Quin, 1978; Feigin *et al.,* 1991; Pescod, 1992; Al Salem, 1996; Biswas *et al.,* 1999; Yadav *et al.,* 2002) although such practice is traditionally still affected by problems of public acceptance (Pollice *et al.,* 2004). Nevertheless, Hespanhol (1999) emphasized that the utilization of new water sources is crucial because an increase of sustainable agricultural production may not be attained simply by expansion of cultivated areas.

Kiziloglu et al. (2008) investigated the effects of irrigation with untreated, and preliminary and primary treated wastewater on macro- and micronutrient distribution within the soil profile, yield and mineral content of cauliflower and red cabbage plants grown on a calcareous soils.They reported that wastewater irrigation affected significantly soil chemical properties in the 0–30 cm soil layer and plant nutrient content after harvest. In addition, application of wastewater increased soil salinity, organic matter, exchangeable Na, K, Ca, Mg, plant available phosphorus and microelements, and decreased soil pH. Wastewater irrigation treatments also increased the yield as well as N, P, K, Ca, Mg, Na, Fe, Mn, Zn, Cu, Pb, Ni and Cd contents of cauliflower and red cabbage plants. However, problems with wastewater disposal and water scarcity in arid areas can be decreased by using treated wastewater for irrigation. In case of soils with poor fertility, it is an important source of nutrients for crop production (Kiziloglu *et al.*, 2007).

Rahil and Antonopoulos (2007) examined the effects of irrigation with reclaimed wastewater and nitrogen fertilizer applications on plant growth, water and nitrogen distribution in the soil profile, water and nitrogen balance components and nitrogen leaching to groundwater. They concluded that municipal wastewater reclaimed by activated sludge and nitrification/denitrification can be used as valuable source of irrigation without contaminating groundwater. However, this quality of wastewater can replace only a small portion of plant N requirements.

Some investigations demonstrated that the plants play active roles towards mobilizing and uptake of metals bound in soil with considerable differences among plant species and cultivars (Helal, 1990; Hinsley *et al.,* 1978; Mench *et al.,* 1989; Petterson, 1977). Plant characteristics and activities may affect heavy metal uptake in different ways. These include the modification of soil properties related to heavy metal availability, the control of heavy metal transfer across cell membranes, the binding of metals in various plant tissues, and the interaction between the nutritional status of the plant as well as environmental stress conditions with these activities.The objective of the present study was to study the effects of treated wastewater on soil chemical properties and plant growth characteristics as well as accumulation of heavy metals in plant tissues.

MATERIALS & METHODS

As the wastewater reaches Abu Nakhala station at south of Doha, Qatar, it is treated and then discharged into an artificial pond through a pipeline. The pond lies next to the station. The land around the pond – at the margins - is covered with a dense plant cover. The land that is covered with the treated water sometimes gained a dark brown color, which is due to the high alkalinity level of the soil with the pH above 8.The study was conducted at Qatar university greenhouse in the growing season of 2007 using large size pots. Treated wastewater samples were collected from Abu-Nakhala pond, Doha, Qatar once a week for three months period. Pots were filled with a mixture of sand and clay soils with ratio of (1:1). Two crop plants were used in this study; grain sorghum (*Sorghum bicolor* L.) and Sunflower (*Helianthus annuus* L). Plants were irrigated with four different mixtures of treated wastewater (TWW) and sea water (SW) (1:0, 1:1, 3:1, and 0:1) in addition to potable tap water (PTW) as a control. The water characteristics were determined prior to irrigation treatment application. At the end of the experiment, composite soil samples from each pot were taken and prepared for analysis. Plant samples from each treatment were washed with de-ionized water, followed by cleaning with a dilute solution of 0.005% HCl and then they were thoroughly washed, by means of a special detergent (alconox 0.1%), and rewashed repeatedly (four times) with distilled water, left to drain on a filter paper, and dried in a ventilated oven at 70 °C. They were then ground by means of a special hammer mill, and were ready for chemical analysis.

Samples chemical analyses were carried out as described in standard methods (APHA, 1989) in order to determine electrical conductivity (EC), pH, total dissolved solids (TDS), total nitrogen (N), phosphate (P), sodium (Na), potassium (K), calcium (Ca), magnesium (Mg) contents.In addition heavy metals such as cadmium (Cd), zinc (Zn), copper (Cu), lead (Pb), chromium (Cr) and other elements were determined using Spectrophotometer and its ready kits.The core facilities of the Central Agricultural laboratory in Doha was used for water, soil and plant samples chemical analyses The results of soil and plant analyses were submitted to analyses of variance. The statistical analyses were performed for water treatments and crop plants. Variables showing significant F-test ($P < 0.05$) were submitted to mean comparisons by L.S.D. test ($P < 0.05$). All statistical analyses were carried out using the Minitab program.

RESULTS & DISCUSSION

Quality of treated wastewater, sea water and potable tap water used for irrigation are shown in Table 1. The composition of the potable tap water was less variable than that of both treated wastewater and sea water. The chemical characteristics of treated waste water were in general satisfactory. On an average basis the pH, EC and TDS were higher in treated wastewater than that of potable tap water but still very little compared to sea water (Table 1). Nutrient concentrations and heavy metals in the treated waste water appear to be under the critical limits. Cd, Pb and all other elements concentrations in TWW found to be in the acceptable range based on FAO standards (Pescod, 1992).Some chemical properties of the soil after irrigation with treated wastewater, mixture of TWW plus sea water, sea water and portable tap water are shown in (Table 2). The pH and EC of soil irrigated with 100 % treated waste water were in the acceptable limits according to FAO standard levels (Pescod, 1992).

Anions and Cations were in their lowest concentration on soil irrigated with PTW than both of TWW, mixture of TWW and SW and SW. The concentrations of anions and cations were increased gradually starting from treated wastewater passing through the mixture of TWW and SW reaching to their highest level on soil irrigated with 100 % Sea water. The differences between control treatment and each other treatment were statistically significant based on LSD test except for N %. The two crop plants (Sorghum and Sunflower) did not show significant differences in concentration of anions and cations in their soils. The concentration of micro elements and heavy metals in the soil due to irrigation with wastewater and other water irrigation treatments and two crop plants at the end of growing season

Table 1. Water samples chemical characteristics used in the experiment

Water type	pH	EC MS/Cm	TDS (mg/L)	Anion meq/L			Cations meq/L			
				HCO_3	Cl	SO_4	Ca	Mg	Na	K
TWW	8.34	12.43	7460	60.97	60.97	93	51.37	70.9	70.9	3.12
SW	8.28	57.6	34500	3.09	585.86	296.78	25.24	190.55	656	13.13
PTW	8.16	0.17	104.7	1.69	0.52	0	0.95	0.09	0.5	0.08
	Total Elements (mg/L)									
	Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	Cd	Pb
TWW	0.0021	0.0094	0.001	5.084	0.0014	0.0133	0.0303	0.0086	0.0002	0.0016
SW	0.0018	0.051	0.0004	2.51	0.0008	0.0037	0.205	0.0206	0.0002	0.0048
PTW	0.0523	0.072	0.028	3.103	0.0209	0.0542	0.757	0.0236	0.0002	0.0021

EC: Electrical conductivity M.Mhos/cm (at 25°C), TDS: Total Dissolved Solids
TWW: Treated Waste Water; SW: Sea Water; PTW: Potable Tap Water

is shown in Table 3. Cr, Mn and Zn showed significant differences between soil irrigated with portable tap water and other irrigation treatments. On the other hand, Al, Fe, Ni, Co, Cu, As, Cd and Pb did not show significant differences among the irrigation water treatments. These results are in agreement with other researchers. Boll et al. (1986) reported that irrigation using wastewater irrigation increased the concentration of Zn to toxic levels in the soil. Abedi-Koupai et al. (2006) found that application of wastewater treatment had no significant effect on the accumulation of soil Fe, Cd, Ni, Cu and Zn.Table 2.Soil physical and chemical characteristics in the end of the experiment.

In general, there were significant differences between heavy metals in soil for the two crop plants. Sorghum soils have significantly less concentration of Co, Cu and As compared to that of Sunflower soils (Table 3). Many studies showed that vegetation is an important factor influencing the mobility of metals in soil, directly as well as indirectly (Caron *et al.*, 1996). Plants may increase metal mobility through the formation of preferential pathways along root channels or the complex of metals with root exudates in the rhizome. On the other hand, they may also retard metal leaching through reducing deep seepage by taking up water, adsorption of metals to root surfaces, plant uptake of metals, and simulated microbial immobilization in rhizome (McBride *et al.*, 1997).

Sorghum was found to accumulate significantly higher concentration of Mn and Zn (72.47 and 92.00 mg/L, respectively) than that of Sunflower. On the other hand, Sunflower has significantly higher concentration of Cr compared to that of Sorghum (Table 4). Murillo et al. (1999) studied the accumulation of chemical elements in soil and in two crops - sunflower and sorghum - affected by heavy metals spill. They reported that leaves of spill-affected crop plants had higher nutrient (K, Ca and Mg for sunflower and N and K for sorghum) concentrations than controls, indicating a 'fertilizing' effect caused by the sludge. Seeds of spill-affected sunflower plants did accumulate more As, Cd, Cu and Zn than controls, but values were below toxic levels. Leaves of sorghum plants accumulated more As, Bi, Cd, Mn, Pb and Zn than controls, however these values were also below toxic levels for livestock consumption. In general, none of the heavy metals studied in both crops reached either phototoxic or toxic levels for humans or livestock.

Table 2. Soil physical and chemical characteristics in the end of the experiment

Crop plant	Water treatment	pH	EC MS/Cm	CEC meq/100g	Macro Nutrients			Anions meq/L			Cations meq/L		
					N %	P mg/L	K mg/L	HCO_3	Cl	SO_4	Ca	Mg	Na
Sorghum	T1	7.4	5.0	12.67	0.12	6.87	0.97	1.923	22.29	32.51	23.47	8.96	23.47
	T2	7.4	13.2	13.27	0.09	7.77	2.17	2.02	92.78	60.07	96.53	22.26	96.53
	T3	7.4	11.7	5.73	0.10	9.23	1.97	1.91	76.21	58.46	78.97	21.32	78.97
	T4	7.4	27.9	10.80	0.12	10.09	4.97	1.72	227.37	118.03	243.87	48.92	243.87
	C	7.9	1.4	3.47	0.13	9.16	0.37	1.52	6.07	6.97	4.70	2.38	4.70
	Mean	**7.5**	**11.8**	**9.19**	**0.11**	**8.62**	**2.07**	**1.87**	**84.98**	**55.19**	**89.57**	**20.772**	**89.57**
Sunflower	T1	7.3	6.8	5.53	0.15	9.47	1.52	1.67	31.63	47.37	33.63	13.57	33.63
	T2	7.4	14.1	4.47	0.13	8.30	2.34	1.57	98.25	63.92	101.73	23.37	101.73
	T3	7.5	13.5	2.33	0.13	8.28	2.31	1.47	89.57	67.27	94.56	20.47	94.56
	T4	7.4	22.9	17.73	0.10	10.59	3.97	1.77	179.36	105.64	198.23	43.42	198.23
	C	7.9	0.8	12.13	0.09	10.66	0.17	1.67	2.67	4.05	1.73	0.83	1.73
	Mean	**7.5**	**11.7**	**8.44**	**0.12**	**9.00**	**2.06**	**1.63**	**80.27**	**57.65**	**85.98**	**20.37**	**85.98**

Soil solution: Soil : Water = 5:1. EC: Electrical conductivity M.Mhos/cm (at 25°C)

Table 3. Soil chemical analysis in the end of the experiment

Crop plant	Water treatment	Total Elements (mg/L)										
		Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Cd	Pb
Sorghum	T1	2449	18.77	80.33	3312	8.20	13.27	15.59	50.84	17.68	13.07	9.24
	T2	3256	5.18	72.43	3621	1.06	1.11	29.53	17.49	8.37	0.0002	0.02
	T3	2633	3.10	64.35	3163	1.82	0.02	62.50	29.98	9.47	0.0002	0.02
	T4	2943	4.67	64.29	3499	4.11	0.02	87.42	30.91	11.87	0.0002	0.02
	C	2828	4.07	66.94	3274	8.59	1.22	99.21	17.76	18.07	0.0002	0.02
	Mean	**2822**	**7.17**	**69.67**	**3374**	**4.76**	**3.11**	**58.85**	**29.39**	**13.03**	**2.61**	**1.84**
Sunflower	T1	2689	3.09	62.12	3128	13.83	5.31	254.40	11.10	29.22	0.02	0.0002
	T2	3067	4.47	81.48	3659	23.24	8.08	206.53	23.42	41.74	0.02	0.0002
	T3	2952	4.03	69.10	3427	23.20	1.63	261.37	6.99	50.27	0.02	0.02
	T4	2593	3.67	65.36	3270	24.31	4.29	355.83	21.25	53.53	0.02	0.02
	C	2566	4.462	62.66	3182	15.92	0.13	211.36	7.12	35.54	0.27	2.87
	Mean	**2773**	**3.9418**	**68.14**	**3333**	**20.11**	**3.89**	**257.89**	**13.97**	**42.06**	**0.04**	**0.56**
	LSD 0.05	**ns**	**5.19t**	**8.37t**	**ns**	**4.11p**	**ns**	**56.83p**	**11.96**	**9.17p**	**ns**	**Ns**

ns: not significant; t: water treatment; p: crop plant

Table 4. Plant chemical analysis in the end of the experiment

Crop plant	Water treatment	Total Elements (mg/L)										
		Al	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Cd	Pb
Sorghum	T1	2.77	34.40	98.16	41.76	0.0002	0.0002	306	141	28.68	0.0002	0.0002
	T2	0.02	57.04	74.04	55.15	0.0002	0.0002	257	67	44.25	0.0002	0.0002
	T3	2.84	33.31	61.09	42.15	0.0002	0.0002	175	72	24.73	0.0002	0.0002
	T4	16.51	40.13	54.47	95.75	0.0002	0.0002	242	54	26.73	0.0002	0.0002
	C	0.02	22.17	74.64	53.58	0.0002	0.0002	306	126	59.77	0.0002	0.0002
	Mean	**4.41**	**37.43**	**72.47**	**57.68**	**0.0002**	**0.0002**	**257**	**92**	**36.87**	**0.0002**	**0.0002**
Sunflower	T1	0.02	30.22	18.42	235.53	0.0002	0.0002	253	103	25.39	0.0002	0.0002
	T2	0.02	48.08	11.36	51.60	0.0002	0.0002	219	57	22.27	0.0002	0.0002
	T3	0.02	45.44	25.49	30.21	0.0002	1.3647	233	45	35.63	0.0002	0.0002
	T4	0.02	56.46	15.67	36.73	0.0002	0.0002	244	34	28.24	0.0002	0.0002
	C	0.02	58.40	13.25	19.96	0.0002	0.0002	263	65	25.44	0.0002	0.0002
	Mean	**0.02**	**47.72**	**16.84**	**74.81**	**0.0002**	**0.27353**	**242**	**61**	**27.38**	**0.0002**	**0.0002**
	LSD 0.05	**ns**	**9.83p**	**8.72p**	**ns**	**ns**	**ns**	**ns**	**16.29p**	**ns**	**ns**	**ns**

ns: not significant; t: water treatment; p: crop plant

CONCLUSION

Sorghum soil irrigated with treated waste water has less concentration of heavy metals such as Co, Cu and As.Moreover, Sorghum tissue found to have accumulation of heavy metals as Mn and Zn.So far the concentrations did not reach the toxic levels.Thus, from the results of this study we recommend that sorghum plants could be used as phyto-remediation candidates to screen the level of heavy metals in polluted areas as well as to reduce the heavy metal levels of such polluted areas.

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