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EFFECTS OF MUNICIPAL WASTEWATER ON ACCUMULATION OF HEAVY METALS IN SOIL AND WHEAT (*TRITICUM AESTIVUM* L.) WITH TWO IRRIGATION METHODS

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ABSTRACT

A study was carried out to investigate the effects of municipal wastewater on accumulation of heavy metals in soil and wheat (*Triticum aestivum* L.) with two irrigation methods. Soil samplings of 0 to 20 cm depth were taken from Fereydoonshahr area in Isfahan province in the center of Iran. Wheat was transplanted in these soils. The experiment consisted of four treatments including soil irrigation with water by FI (Flooding Irrigation) (T1) and DI system (Drip Irrigation) (T2), soil irrigation with wastewater by FI (T3) and DI system (T4). Soil characteristics such as soil reaction (pH), electrical conductivity (EC), organic matter (OM), extractable Fe, manganese, nickel and cadmium were measured before and after the test. After 40 days, samples were taken for testing. The evidences provided by this experiment indicated that urban wastewater caused increase of heavy metals in wheat with both irrigation methods. Accumulation of heavy metals in roots was more than in shoots in FI and DI system. These results showed that the accumulation of heavy metals in wheat in FI system was more important than in DI system.

Key words: Cadmium, heavy metals, Manganese, Nickel, irrigation methods, wheat.

INTRODUCTION

Water is a scarce commodity in the Middle East and North Africa (MENA) and its availability is declining to a crisis level. The reuse of wastewaters for purposes such as agricultural irrigation can reduce the amount of water that needs to be extracted from environmental water sources (Heidarpour et al., 2007).

In arid and semi-arid regions, water resources of good quality are becoming scarcer and are being allocated with priority for urban water supply. Therefore, there is an increasing necessity to irrigate with water that already contains salts, such as saline groundwater, drainage water, and treated wastewater (Jalali et al., 2007).

Land application of treated wastewater (TWW) on cultivated fields may serve as a viable way of disposing of effluents, and sustaining agricultural production in regions experiencing shortage in fresh water. However, irrigation with TWW is not free of risk both to crop production and soil environment (Bhardwaj et al., 2007).

Using large-scale wastewater irrigation on agricultural lands can be a synergistic management practice. The wastewater will have a different fate than being pumped into a river, agricultural crops can make use of the extra water and nutrients and groundwater recharge is yet another positive outcome of wastewater irrigation (Walker and Lin, 2008).

However, wastewater contains substantial amounts of toxic heavy metals, which create problems. Excessive accumulation of heavy metals in agricultural soils through wastewater irrigation may not only result in soil contamination, but also affect food quality and safety. Food and water are the main sources of our essential metals; these are also the media through which we are exposed to various toxic metals. Heavy metals are easily accumulated in the edible parts of plants (Arora et al., 2008).

Application of wastewater to cropland and forested lands is an attractive option for disposal, because it can improve the physical properties and the nutrient content of soils. Wastewater irrigation provides water, N and P, as well as organic matter to the soils, but

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there is a concern about the accumulation of potentially toxic elements such as Cd, Cu, Fe, Mn, Pb and Zn from both domestic and industrial sources (Kiziloglu et al., 2008).

Determination of the rate of mobilization of heavy metal from sewage sludge or wastewater after its application to soil is very important for agricultural practice, since is allows us to assess the rate at which they pass into the soil solution, which conditions their uptake by plants (Gondek, 2010).

Kiziloglu et al. (2008) investigated the effects of untreated and treated wastewater irrigation on some chemical properties of cauliflower (*Brassica olerecea* L. var. *botrytis*) and red cabbage (*Brassica olerecea* L. var. *rubra*) grown on calcareous soil in Turkey. Their results showed that the 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.

Najafi and Nasr (2009) investigated comparatively the effects of wastewater on soil chemical properties in three irrigation methods. The results showed that the application of wastewater in DI (Drop Irrigation) caused an increase of EC, OM, SO_4, Ca, Na, Cl and a decrease of hydraulic conductivity, porosity, Pb and moisture point of soil DI and FW (Fresh Water) treatments.

Karami et al. (2008) investigated the effects of municipal sewage sludge on the concentration of Lead (Pb) and Cadmium (Cd) in soil and on yield of wheat. Their results showed that the application of sewage sludge cause increase of extractable cadmium and lead in soil.

These results also showed the application of sewage sludge caused an increase of concentration of cadmium and lead concentration in root and shoot of wheat.

The aim of this research was to assess the effects of municipal wastewater on accumulation of heavy metals in wheat with two irrigation methods.

MATERIAL AND METHODS

Site description, sample preparation

Soil samples of 0 to 20 cm depth were taken from Fereydoonshahr area in Isfahan province in the center of Iran. Wheat was transplanted in these soils. The experiment was carried out at green house in 2010.

The experiment consisted of four treatments including soil irrigation with water by FI (Flooding Irrigation) (T1) and DI system (Drip Irrigation) (T2), soil irrigation with wastewater by FI (T3) and DI system (T4). Samples were taken for testing, after 45 days.

The plant tissues were prepared for laboratory analysis by Wet Digestion method (Campbell and Plank, 1998).

Laboratory determinations

Soil characteristics such as soil reaction (pH), electrical conductivity (EC), organic matter (OM), DTPA-extractable Fe, manganese (Mn), nickel (Ni) and cadmium (Cd) were measured before and after the test. Soil pH and EC were measured on 1:1 extract (Soil:Water). Soil OM was determined as in Walkley and Black (ASA, 1982). Extractable heavy metals in soil samples and plant samples were carried out by DTPA in accordance the Standard Methods (APHA, 1998).

Statistical analysis

Descriptive statistical analysis, including mean comparison using Duncan’s Multiple Range Test (DMRT), was conducted using SPSS software.

RESULTS AND DISCUSSION

Main soil, water and wastewater, properties before experiment are shown in table 1.

The soil chemical characteristics in the four treatments can be compared in table 2.

Minimum EC (dS/m) equal to 1.09 was recorded in T1, and maximum EC equal to 1.23 was related to T3. Minimum pH equal to 6.96 was related to T3, and maximum pH equal to 7.09 was found in T1 and T2.

Minimum TN (%) equal to 0.09 was recorded in T1 and T2, and maximum TN equal to 0.24 was related to T3. Minimum extractable Fe (ppm) equal to 2.05 was observed in T1, and maximum extractable Fe equal to 2.32 was found in T3. Minimum extractable Mn (ppm) equal to 1.48 was recorded in T1, and maximum extractable Mn equal to 1.96 was determined in T3. Minimum extractable Cd (ppm) equal to 0.09 was recorded in T1 and T2, and maximum extractable Cd equal to 0.13 was observed in T3. Minimum extractable Ni (ppm) equal to 0.29 was determined in T1, and maximum extractable Ni equal to 0.39 was determined in T3.

Municipal wastewater contains a variety of inorganic substances from domestic and industrial sources, including a number of potentially toxic elements such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), zinc (Zn), etc. (Khai et al., 2008).

According to table 2, soil irrigation with wastewater increased EC, TN, Fe, Mn, Cd and Ni but it decreased pH. The increase of heavy metals content in soil in FI system was higher than in DI system.

Table 1. Main soil, water and wastewater properties

pH	EC (dS m^{-1})	N (ppm)	BOD_5 (ppm)	K (ppm)	Ca (me L^{-1})	Mg (me L^{-1})	Na (me L^{-1})	Fe (ppm)	Mn (ppm)	Cd (ppm)	Ni (ppm)
Soil											
7.07	1.00	0.09	-	2.45	-	-	21.11	2.07	1.49	0.07	0.30
Water											
7.00	0.33	0	-	0.01	2.00	1.10	0.30	0.001	0.00	0.00	0.00
Wastewater											
6.92	1.17	29.10	25.90	26.61	3.71	2.90	7.72	0.359	0.076	0.067	0.026

Table 2. Comparing the means for soil chemical characteristics

pH	EC (dS m^{-1})	N (%)	Fe (ppm)	Mn (ppm)	Cd (ppm)	Ni (ppm)
T1 (Soil irrigation with water by FI system)						
7.09a+	1.09a	0.09a	2.05a	1.48a	0.09a	0.29a
T2 (Soil irrigation with water by DI system)						
7.09a	1.14b	0.09a	2.07b	1.49a	0.09a	0.30a
T3 (Soil irrigation with wastewater by FI system)						
6.96b	1.23c	0.24b	2.32c	1.96b	0.13b	0.39b
T4 (Soil irrigation with wastewater by DI system)						
7.00c	1.18d	0.20c	2.26d	1.90c	0.11c	0.36c

+ Numbers followed by same letters in each column are not significantly ($P<0.05$) different according to the DMR test

The effects of wastewater on soil properties

Soil reaction (pH)

Irrigation with wastewater decreased soil pH. The reason is likely due to the decomposition of organic matter and production of organic acids in soils irrigated with wastewater (Vaseghi et al., 2005). This is in line with findings of Vaseghi et al. (2005) and Khai et al. (2008).

Some investigations showed that the soil irrigation with wastewater increased soil pH (Rusan et al., 2007; Rattan et al., 2005). Most these investigations described the long term impact of irrigation with sewage and wastewater effluents on soil properties while our study was short term. Soil irrigation with wastewater may cause at first a decrease of soil pH, but after a while it may cause an increase of soil pH.

Electrical conductivity (EC)

Irrigation with wastewater increased EC. The higher concentration of cations such as Na and K in wastewater led to an increase in EC and exchangeable Na and K in soils irrigated with wastewater (Khai et al., 2008). This is in line with findings of Rusan et al. (2007), Jahantigh (2008) and Khai et al. (2008).

Total nitrogen (TN)

Irrigation with wastewater increased TN. Increasing the total N of soil irrigated with wastewater can be attributed to the presence of different forms of N in the wastewater. This is in line with findings of Rusan et al. (2007) and Khai et al. (2008).

Micronutrients and heavy metals

Many investigations, including long and short term studies, showed that the accumulation of heavy metals in soil increased as a consequence of the application of wastes such as pig slurry, wastewater, sewage sludge, etc.

Our results showed that:

- Irrigation with wastewater increased extractable Fe. This is in line with findings of Rusan et al., (2007) and Vaseghi et al. (2005).
- Irrigation with wastewater increased extractable Mn. This is in line with findings of Rusan et al., (2007) and Jahantigh (2008).
- Irrigation with wastewater increased extractable Cd. This is in line with findings of Mapanda et al. (2005), Khai et al. (2008) and Jagtab et al. (2010).
- Irrigation with wastewater increased extractable Ni. This is in line with findings of Mapanda et al. (2005) and Jagtab et al. (2010).

Accumulation of micronutrients and heavy metals from wastewater application could be caused directly by the wastewater composition or indirectly through increasing solubility of the indigenous insoluble soil heavy metals as a result of the chelation or acidification action of the applied wastewater (Rusan et al., 2007).

Some investigations showed that irrigation with wastewater does not have effect on soil extractable concentration of cadmium and nickel (Rusan et al., 2007; Vaseghi et al., 2005). In these investigations the smaller effect of wastewater on the extractable cadmium and nickel may be due to the small amount of cadmium and nickel in the applied sewage sludge and wastewater.

Data on the extractable concentration of heavy metals in wheat plants in the four applied treatments can be seen in table 3.

Table 3. Comparing the accumulation of heavy metals in wheat in the four applied treatments

Fe (ppm)	Mn (ppm)	Cd (ppm)	Ni (ppm)
T1 (Soil Irrigation with Water by FI system)			
Root			
1.697a+	0.701a	0.008a	0.009a
Shoot			
1.101e	0.381e	0.00e	0.00e
T2 (Soil Irrigation with Water by DI system)			
Root			
1.661b	0.667b	0.008a	0.009a
Shoot			
1.030f	0.330f	0.00e	0.00e
T3 (Soil Irrigation with wastewater by FI system)			
Root			
2.003c	0.874c	0.017b	0.016b
Shoot			
1.246g	0.480g	0.009f	0.008f
T4 (Soil Irrigation with wastewater by DI system)			
Root			
1.851d	0.850d	0.013c	0.012c
Shoot			
1.147h	0.424h	0.006g	0.005g

+ Numbers followed by same letters in each column are not significantly ($P<0.05$) different according to the DMR test

Minimum extractable concentration of Fe (ppm) in root, equal to 1.661, was determined in T2, and maximum extractable Fe equal to 2.003 was found in T3. Minimum extractable Mn (ppm) in root equal to 0.667 was recorded in T2, and maximum extractable Mn equal to 0.874 was related to T3. Minimum extractable Cd in root (ppm) equal to 0.008 was observed in T1 and T2, while maximum extractable Cd equal to 0.017 was noticed in T3. Minimum extractable Ni in root (ppm) equal to 0.009 was determined in T1 and T2, while maximum extractable Ni equal to 0.016 was found in T3.

The increase of heavy metals concentrations in wheat plants in FI system was higher than in DI system. In all cases the accumulation of heavy metals in root was higher than in shoot.

The changes of heavy metal uptake by plants were related to the changes in the physicochemical characteristics of soil following the application of wastewater.

The effects of wastewater on accumulation of micronutrients and heavy metals in wheat

As mentioned before, addition of wastewater to soil caused an increase in extractable concentration of heavy metals. Therefore, irrigation with wastewater increases the amount of uptake and accumulation of heavy metals in plant.

Many investigations, including long and short term studies, showed that the accumulation of heavy metals in plants increased as a consequence of the application of wastes such as wastewater, sewage sludge.

Our results showed that:

- Extractable Fe in wheat irrigated with wastewater increased. This is in line with findings of Arora et al. (2008), Vaseghi et al. (2003) and Abd Elnaim and El Nashar (1988).
- Extractable Mn in wheat irrigated with wastewater increased. This is in line with findings of Arora et al. (2008), Vaseghi et al. (2003) and Abd Elnaim and El Nashar (1988).
- Extractable Cd in wheat irrigated with wastewater increased. This is in line with findings of Rusan et al., (2007), Vaseghi et al. (2003) and Jagtab et al. (2010).
- Extractable Ni in wheat irrigated with wastewater increased. This is in line with findings of Jagtab et al. (2010), Vaseghi et al. (2003) and Abd Elnaim and El Nashar (1988).

Arora et al. (2008) observed that the concentration of all the heavy metals is higher in wastewater-irrigated vegetables than in freshwater-irrigated plants.

Accumulation of micronutrients and heavy metals as a result of wastewater application could be caused directly by the wastewater composition or indirectly through increasing solubility of the indigenous insoluble soil heavy metals as a result of the chelation or acidification action of the applied wastewater (Rusan et al., 2007).

The bioavailability of heavy metals depends on different factors such as soil pH and amount of clay in soil. An increase of soil pH and amount of clay can decrease the uptake of heavy metals by wheat. In presence of organic matter, heavy metals can be found as chelates, which increase the ability of wheat to uptake heavy metals. Irrigation of soil by wastewater increases soil organic matter and decrease soil pH. Therefore, the uptake of heavy metals by plants increases.

CONCLUSIONS

The reuse of wastewaters for purposes such as agricultural irrigation reduces the amount of water that needs to be extracted from environmental water sources. Using large-scale wastewater irrigation on agricultural lands can be a synergistic management practice. On the other hand, urban wastewater caused an increase of heavy metals in wheat, in both irrigation methods, but less with drip irrigation.

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