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Heavy elements in soils and wastewater influence

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Abstract: In this paper, impacts of urban wastewater and leachate on accumulation of iron (Fe), manganese (Mn), zinc (Zn), nickel (Ni) and cadmium (Cd) in soil and barley (Hordeum vulgare L) is studied. The experiment consisted of four treatments including soil irrigated with 300 ml of water (control, T1), soil irrigated with 300 ml of wastewater (T2), soil irrigated with 300 ml of 70% (T3) and 90% (T4) waste leachate to water (V/V) ratios. After 40 days, samples were taken for testing. The concentrations of extractable Fe, Mn, Zn, Cd and Ni (ppm) in soil under T2 were 2.27, 2.04, 1.27, 0.063 and 0.382, they (ppm) in soil under T3 were 2.89, 2.25, 1.79, 0.181 and 0.432, and they (ppm) in soil under T4 were 3.74, 3.31, 2.97, 0.261 and 0.601, respectively. In the barley under the treatments, the concentrations of extractable Fe, Mn, Zn, Cd and Ni (ppm) in roots under T2 were 2.011, 0.942, 0.708, 0.012 and 0.015, they (ppm) in roots under T3 were 2.912, 1.323, 0.985, 0.037 and 0.039, and they (ppm) in roots under T4 were 3.241, 1.996, 1.256, 0.068 and 0.093, respectively. The evidence provided by this experiment indicated that urban wastewater and urban waste leachate caused an increase of extractable heavy metals in soil and barley. Waste leachate application had the more significant effect on accumulation of heavy metals in soil and barley than wastewater application.

Key words: Wastewater; Contamination; Heavy elements

1. Introduction

The second most important problem after the water quality in developing countries is solid waste management (Tiawo, 2010). Landfill is an engineered waste disposal site facility with specific pollution control technologies designed to minimize potential impacts. Landfills are usually either placed above ground or contained within quarries, pits. Landfills are sources of groundwater and soil pollution because of the production of leachate and its migration through refuse. The major environmental problem at landfills is the loss of leachates from the site and the subsequent pollution of groundwater (Alslaibi et al., 2011). In different theories regarding leachate generation in landfills this concept is well developed to calculate the quantity of entered water to the waste body in different ways (Abdoli et al., 2010).

The landfill leachate is one kind of wastewater with high concentration of organic compounds, inorganic compounds and sometimes non-trivial level of toxic pollutants like arsenic and chlorinated organic. The Chemical Oxygen Demand (COD) concentration of typical young leachate can be 36 times as high as the raw domestic wastewater, whereas a mature leachate may be equal in COD concentration to raw sewage, but has more refractory organic constituents than domestic sewage (Tengrui et al., 2007).

The main flows of heavy metals to the environment are from industrial and municipal wastes, both of which contained a variety of toxic heavy metals. The heavy metals commonly found in landfill leachate contain Cr, Cd, Pb, Hg, Ni, Cu, Zn, Fe and Se. The actual number and concentration of heavy metals in the leachate varies from one landfill to another (Chuangcham et al., 2008).

The use of wastes in agriculture and for land, reclamation is increasingly being recognized as an important issue for both soil conservation and residual disposal. Most sewage wastes contain valuable nutrients that could be used to improve soil fertility. Agricultural practices often leads to a gradual decrease in soil organic matter content, with the consequent decrease of soil fertility through an impoverishment of the physical, chemical and biological properties of soils (Antolı´n et al., 2005). Tabatabaei et al. (2007) explained the effect of wastewater on soil; subsurface water and plants completely depend on the type of the wastewater and its content.

Kavitha and Subramanian (2007) investigated the effect of enriched municipal solid waste compost application on growth, plant nutrient uptake and

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yield of rice. Urban solid waste compost has enriched nutrient level, which leads to the continuous availability of nutrients in available form to the plants. The highest grain yield, and straw yield were observed in the treatment combination of 25% of enhanced compost and 75% of recommended dose of inorganic fertilizer (T_5) with value of 5.22 and 8.65 t ha^{-1}, respectively.

The study aim was to evaluate the comparison between impacts of urban wastewater and urban waste leachate applications on accumulation of iron (Fe), manganese (Mn), zinc (Zn), nickel (Ni) and cadmium (Cd) in soil and barley (Hordeum vulgare L).

2. Materials and methods

2.1. Sample preparation

Soil samples of 0 to 10 cm depths were taken from the soil surface and barley was transplanted in these soils. The experiment was carried out at the greenhouse in 2011.The experiment consisted of four treatments including soil irrigated with 300 ml of water (control, T1), soil irrigated with 300 ml of wastewater (T2), soil irrigated with 300 ml of 70% (T3) and 90% (T4) waste leachate to water (V/V) ratios. After 40 days, samples were taken for testing. The plant tissues were prepared for laboratory analysis by Wet Digestion method (Campbell and Plank, 1998). Soil samples were air dried in a greenhouse at a temperature between 25ºC and 30ºC and sifted through a 2-mm mesh sieve for preparation of soil samples (Mojiri and Jalalian, 2011).

2.2. Laboratory determinations

Soil reaction (pH) and electrical conductivity (EC) were measured on 1:1 extract (Soil: Water). Micronutrients and heavy metals in soil and plant samples were carried out by DTPA in accordance the Standard Methods, analysis of urban wastewater and urban waste leachate were carried out in accordance the Standard Methods (APHA, 1998).

2.3. Statistical analysis

Descriptive statistical analysis including mean comparison using Duncan's Multiple Range Test (DMRT) (in 0.05 level) was conducted using SPSS software.

Water, urban wastewater and urban waste leachate properties are shown in Table 1. The soil chemical characteristics in the four treatments can be compared in Table 2. According to Table 1; EC, BOD_5, Fe, Mn, Zn, Cd and Ni in urban waste leachate were more than in urban wastewater.

Table 1
Water, wastewater and waste leachate properties

pH	EC ($dS\ m^{-1}$)	N (ppm)	BOD_5 (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cd (ppm)	Ni (ppm)
Water								
7.02	0.29	0.00	_	0.000	0.000	0.000	0.000	0.000
Wastewater								
6.84	1.26	21.46	24.98	0.431	0.102	0.067	0.023	0.041
Waste leachate								
5.92	28.22	0.59	26.21	77.01	19.91	18.14	0.971	1.832

3. Results and discussion

3.1. Effects of urban waste leachate and wastewater on heavy metals in soil

According to Table 2, Soil irrigation with urban wastewater and urban waste leachate caused an increase of extractable Fe, Mn, Zn, Ni and Cd. This result showed that the urban waste leachate application had the more significant effect on accumulation of these metals in soil than wastewater application.

3.1.1. Iron (Fe)

Iron in soil exits in ferrous (Fe^{2+}) and ferric (Fe^{3+}) forms. Soil pH and aerations status of the soil determine, which form predominates. Soil pH, soil aeration, reactions with organic matter, and plant adaptations influence iron availability. The concentration of iron in the soil solution decreases sharply as the soil pH increases. Organic matter improves iron availability by combining with iron, thereby reducing chemical fixation or precipitation of iron as ferric hydroxide. This reduction in fixation and precipitation results in higher concentrations of iron remaining in the soil solution, available for root absorption (Schulate, 2004a). In this research, minimum extractable Fe (ppm) equal to 2.11 was recorded in T1, and maximum extractable Fe equal to 3.74 was observed in T4. Soil irrigation with wastewater and waste leachate increased extractable Fe. This is in line with findings of Galavi et al. (2010) and Panahpour et al. (2011). Wastewater and waste leachate application decreased soil pH but increased soil organic matter; it could be effective on increasing extractable iron. And there was iron in urban wastewater and urban waste leachate.

3.1.2. Manganese (Mn)

Manganese reactions in soils are quite complex. The amount of available manganese is influenced by soil pH, organic matter content, moisture, and soil reaction. Manganese availability increases as soil pH decreased. Manganese toxicity is common in acid soils below pH 5.5. On the other hand, manganese deficiency is most common in soils with a pH above 6.5. As the organic matter content increases, the amount of exchangeable manganese decreases due to increased formation of organic matter and manganese complexes (Schulate and Kelling, 2004). In this research, minimum extractable Mn (ppm) equal to 1.66 was recorded in T1, and maximum extractable Mn equal to 3.31 was observed in T4. Soil irrigation with wastewater increased extractable Mn. This is in line with findings of Galavi et al. (2010). Wastewater and waste leachate application decreased soil pH but increased soil organic matter; it could be effective on increasing extractable manganese. And there were manganese in urban wastewater and urban waste leachate.

3.1.3. Zinc (Zn)

Zinc ions (Zn^{2+}) are held on the surface of clay and organic matter particles. The primary factors affecting zinc availability are soil texture, soil pH, soil phosphorus, soil organic matter and weather conditions. Soil acidity (pH) influences the availability of zinc more than any other factor, with low zinc solubility as the pH increases.

Therefore, zinc deficiency usually is limited with a pH above 6.5. Soil organic matter was hold zinc in a chelated form. Chelation is a process by which certain metals are held within the structure of large organic molecules (Schulate, 2004b). In this research, minimum extractable Zn (ppm) equal to 1.12 was recorded in T1, and maximum extractable Zn equal to 2.97 was observed in T4. Soil irrigation with wastewater and waste leachate increased extractable Zn. This is in line with findings of Galavi et al. (2010) and Panahpour et al. (2011). Wastewater and waste leachate application decreased soil pH but increased soil organic matter; it could be effective on increasing extractable zinc. And there was zinc in urban wastewater and urban waste leachate.

Table 2
Comparing the means for soil chemical characteristics

pH	EC (dS m^{-1})	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cd (ppm)	Ni (ppm)
			T1			
7.16a	1.27a	2.11a	1.66a	1.12a	0.041a	0.310a
			T2			
6.98b	1.33b	2.27b	2.04b	1.27b	0.063b	0.382b
			T3			
6.87c	1.93c	2.89c	2.25c	1.79c	0.181c	0.432c
			T4			
6.71d	2.29d	3.74d	3.31d	2.97d	0.261d	0.601d

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

3.1.4. Cadmium (Cd)

Cadmium in agricultural soils is, likewise relatively immobile under normal conditions, but could become more mobile under certain conditions such as increased soil acidity, and its cadmium level may be enhanced by the usage of phosphate fertilizers, manure or sewage sludge (Cadmium, 2011). In this research, minimum extractable Cd (ppm) equal to 0.041 was recorded in T1, and maximum extractable Cd equal to 0.261 was observed in T4. Soil irrigation with wastewater and waste leachate increased extractable Cd. This is in line with findings of Galavi et al. (2010) and Panahpour et al. (2011).

Wastewater and waste leachate application decreased soil pH but increased soil organic matter; it could be effective on increasing extractable cadmium. And there was cadmium in urban wastewater and urban waste leachate.

3.1.5. Nickel (Ni)

In this research, minimum extractable Ni (ppm) equal to 0.31 was recorded in T1, and maximum extractable Ni equal to 0.601 was observed in T4. Soil irrigation with wastewater and waste leachate increased extractable Ni. This is in line with findings of Galavi et al. (2010) and Panahpour et al. (2011). Wastewater and waste leachate application decreased soil pH but increased soil organic matter; it could be effective on increasing extractable nickel. And there was nickel in urban wastewater and urban waste leachate.

Mojiri (2011) reported; soil irrigated with wastewater caused an increase of electrical conductivity (EC), phosphorus (P), organic matter (OM), total nitrogen (TN), potassium (K), sodium (Na), chloride (Cl), iron (Fe), cadmium (Cd) and zinc (Zn) but it caused a decrease of soil pH.

Burun et al. (2006) investigated some soil properties of lime stabilized urban wastewater and effects on barley's yield and mineral matter content. This result showed significantly increases on the P (mg kg^{-1}) and K (mg kg^{-1}) contents of soils and N (g kg^{-1}), P (g kg^{-1}), K (g kg^{-1}), Ca (g kg^{-1}), Fe (mg kg^{-1}), Mn (mg kg^{-1}), Cu (mg kg^{-1}) and Zn (mg kg^{-1}) contents of leaves were observed. Increasing the doses of wastewater applications effected yield components positively. As a result of high dose application, a significant yield increase was also observed.

Some investigations showed that the irrigation with wastewater does not have effect on soil extractable concentration of cadmium and nickel (Rusan et al., 2007; Vaseghi et al., 2005).

Aryabod et al. (2006) investigated the effects of municipal waste compost leachate on yield and trace elements uptake by lettuce and maize in calcareous and non-calcareous soils.The results of soil analysis showed that irrigation with leachate decreased soil pH significantly and increased soil electrical conductivity, organic carbon and soluble Na and K ($P<0.05$). Leachate application also increased DTPA-extractable Fe, Zn and Mn.

Accumulation of heavy metals as a result of urban wastewater and urban waste leachate application could be caused directly by the wastewater and waste leachate 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 and waste leachate.

3.2. Effects of Urban Waste Leachate and Wastewater on Accumulation of Heavy Metals in Barley

According to Table 3, barley irrigation with urban wastewater and urban waste leachate caused an increase of extractable Fe, Mn, Zn, Ni and Cd. This result showed that the urban waste leachate application had the more significant effect on accumulation of these metals in barley than urban wastewater application. According to the comparison (Table 3), it is clear that among micro elements and heavy metals, the highest amount is related to Fe absorption, in fact, it seems that adding municipal wastewater and waste leachate to the soil provides the exchangeable form of this element for plant uptake more than other micro elements. This result also showed accumulation of heavy metals in roots was important in shoots.

Table 3

Comparing the accumulation of heavy metals in barley in the four applied treatments

Fe (ppm)	Mn (ppm)	Zn (ppm)	Cd (ppm)	Ni (ppm)
		T1		
		Root		
1.703a	0.706a	0.501a	0.004a	0.007a
		Shoot		
1.009b	0.369b	0.208b	0.000b	0.000b
		T2		
		Root		
2.011c	0.942c	0.708c	0.012c	0.015c
		Shoot		
1.297d	0.424d	0.341d	0.008d	0.008d
		T3		
		Root		
2.912e	1.323e	0.985e	0.037e	0.039e
		Shoot		
1.421f	0.603f	0.411f	0.010f	0.011f
		T4		
		Root		
3.241g	1.996g	1.256g	0.068g	0.093g
		Shoot		
1.967h	0.816h	0.613h	0.016h	0.019h

+ 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 shoot, equal to 1.009, was determined in T1, and maximum extractable Fe equal to 1.967 was found in T4. Minimum extractable Mn (ppm) in shoot equal to

0.369 was recorded in T1, and maximum extractable Mn equal to 0.816 was related to T4. Minimum extractable concentration of Zn (ppm) in shoot, equal to 0.208, was determined in T1, and maximum extractable Zn equal to 0.613 was found in T4. Minimum extractable Cd in shoot (ppm) equal to 0.00 was observed in T1, while maximum extractable Cd equal to 0.016 was noticed in T4. Minimum extractable Ni in shoot (ppm) equal to 0.00 was determined in T1, while maximum extractable Ni equal to 0.019 was found in T4.

Minimum extractable concentration of Fe (ppm) in the root, equal to 1.703, was determined in T1, and maximum extractable Fe equal to 3.241 was found in T4. Minimum extractable Mn (ppm) in root equal to 0.706 was recorded in T1, and maximum extractable Mn equal to 1.996 was related to T4. Minimum extractable concentration of Zn (ppm) in the root, equal to 0.501, was determined in T1, and maximum extractable Zn equal to 1.256 was found in T4. Minimum extractable Cd in the root (ppm) equal to 0.004 was observed in T1, while maximum extractable Cd equal to 0.068 was noticed in T4. Minimum extractable Ni in the root (ppm) equal to 0.007 was determined in T1, while maximum extractable Ni equal to 0.093 was found in T4.

These results showed that:

-Irrigation with wastewater increased extractable Fe. This is in line with findings of Mojiri and Amirossadat (2011).

-Irrigation with wastewater increased extractable Mn. This is in line with findings of Mojiri and Amirossadat (2011).

-Irrigation with wastewater increased extractable Zn. This is in line with findings of Galavi et al. (2010).

- Irrigation with wastewater increased extractable Cd. This is in line with findings of Mojiri and Amirossadat (2011).

- Irrigation with wastewater increased extractable Ni. This is in line with findings of Mojiri and Amirossadat (2011).

Mojiri and Aziz (2011) investigated the effects of municipal wastewater on accumulation of heavy metals in soil and wheat (Triticum aestivum L.) with two irrigation methods. These results showed that the urban wastewater caused an increase of heavy metals in wheat with both irrigation methods. Accumulation of heavy metals in roots was more than in shoots.

Antolı´n et al. (2005) reported; cumulative application of sewage sludge to barley crop increased grain yield significantly, which might be associated with improved early establishment of seedlings. The plants had higher dry matter yields and leaf protein concentrations from the beginning of development to ear emergence. These cumulative sewage sludge application plots had lower pH, and increased total organic C (TOC), cation exchange capacity (CEC) and DTPAextractable heavy metals. This treatment also improved soil microbiological properties. Results indicate that relatively low application rates of sewage sludge could be used for several years to maintain crop production in Mediterranean-type climates. However, there was a significant increase of grain heavy metal concentrations that must be taken into consideration under long-term applications of sludge.

These results showed that:

-Irrigation with waste leachate increased extractable Fe. This is in line with findings of Abadi et al. (2011).

-Irrigation with waste leachate increased extractable Mn. This is in line with findings of Abadi et al. (2011).

-Irrigation with waste leachate increased extractable Zn. This is in line with findings of Abadi et al. (2011).

-Irrigation with waste leachate increased extractable Cd. This is in line with findings of Khoshgoftarmanesh and Kalbasi (2001).

-Irrigation with waste leachate increased extractable Ni. This is in line with findings of Khoshgoftarmanesh and Kalbasi (2001).

Khoshgoftarmanesh and Kalbasi (2001) investigated the effect of garbage leachate (GL) on growth and yield of rice and its residual effects on wheat. This result showed that the GL increased concentrations of some heavy metals in rice. Residual effects of GL application after rice increased the straw and grain yield of wheat as well as macro and micronutrients uptake.

According to the comparison (Table 3), it is clear that micro elements and heavy metals is more in soil and barley irrigated with wastewater and waste leachate, therefore, the more municipal wastewater and waste leachate is added, the more absorption is performed by the plant.

4. Conclusion

Municipal waste leachate and municipal wastewater contains macro- and micro elements that can be used by plant. In this research investigated the impact of urban waste leachate and urban wastewater on accumulation of heavy metals in soil and barley. This result showed that municipal wastewater and municipal waste leachate application caused an increase of extractable iron (Fe), manganese (Mn), zinc (Zn), cadmium (Cd) and nickel (Ni) in soil and barley. These results also showed that waste leachate application had the more effect on accumulation of heavy metals in soil and barley than wastewater application.

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