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Impacts of vermicompost on heavy metals accumulation in plant and soil

Hossein Mirzaei[1*]

[1] Instructure, Department of Water Engineering, Agriculture and Natural Resources Campus, Razi University, Kermanshah, Iran

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Corresponding author:
h.mirzaei.t@gmail.com

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Abstract

The present study was conducted to investigate the effect of vermicompost on heavy metals accumulation in plants and soil irrigated with contaminated water at the Campus of the Faculty of Agriculture and Natural Resources of Razi University. The research was carried out in two treatments, using vermicompost and no vermicompost (control) in three replications on the accumulation of copper, iron, zinc, cadmium and manganese in roots, shoots and fruits of tomato and okra plants as well as in two soil layers (0-30 and 30-60 cm). The results indicated that vermicompost application significantly increased the amount of metals in most parts of tomato (fruit: Cu 10.1★★, Fe -11.86★★, Mn 5.97★★; leaves: Fe 8.4★★, Zn 9.73★★, Mn 2.97★; root: Mn -5.56★★) and okra (fruit: Cu 6.73★★, Fe 9.98★★, Zn -7.18★★, Mn 3.06★; leaves: Fe 9.51★★, Zn 6.63★★, Mn 3.84★; root: Cu -9.7★★, Fe -10.2★★, Zn -14★★, Mn -7.12★★). Although vermicompost treatment increased the amount of metals in the soil but it was not significant and only in the first layer the Zn 6.33★★ showed a significant increase. Also, vermicompost prevented moving of metals into the soil. Therefore, simultaneous use of vermicompost and irrigation with contaminated water is not recommended due to increase in heavy metals content in different parts of the studied plants and soil.

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Introduction

Remediation of water and soils contaminated with heavy metals is an important worldwide research field because of increasing necessity to preserve these natural resources. If transported towards aquatic ecosystems, heavy metals can be readily adsorbed by marine animals and directly enter human food chains, thus presenting a high health risks to consumers. They may cause severe dysfunction of the kidney, reproductive system, liver, brain and central nervous system (Manaham, 1994). Cd and Pb are among the main pollutants because of their high toxicity (Matos and Arruda, 2003). Many conventional methods have been proposed for removal of the heavy metals, which involve adsorption, precipitation, chemical oxidation/reduction, reversed osmosis, etc. However, these technologies are expensive and may generate toxic chemical sludge. The use of agricultural waste materials as bio adsorbents of heavy metals with low cost and high efficient technology is also suggested (Sud et al., 2008). At present there are only a few studies regarding the treatment of wastewaters containing heavy metals by vermicompost. Studies of the efficiency of this substrate for removing Cu, Cr, Ni, Zn and Cd from synthetic solutions and electroplating wastes under laboratory conditions reported that Cu, Zn and Ni retention by cattle manure vermicompost from electroplating waste were close to 100%. These studies also reported that it was not necessary to correct the effluent pH during the treatment process to reach the levels recommended by Brazilian legislation for discharge into water courses (Jordao et al., 2002). The potential application of vermicompost to adsorb Cd from both synthetic solution and mineral water was evaluated and showed that vermicompost presented an expressive Cd absorption capacity (38.6 mgg^{-1}) when compared with other adsorbents (Pereira and Arruda, 2003). Another study showed that vermicompost implementation was able to partially improve the negative effects of heavy metals (Mojdehi et al., 2022).

Compared to plant residues, composts have several advantages: reduced volume, slower decomposition rates and recycling of waste (Bernal et al., 2009; De Bertoldi et al., 1983). Several studies (Khwairakpam and Bhargava, 2009; Suthar, 2009, 2010; Suthar and Singh, 2008) pertaining to vermistabilization of sewage sludge have reported increase in total heavy metals content in the vermicompost, whereas some others studies (Abu Bakar et al., 2011; Gupta and Garg, 2008) showed exactly the reverse trend. For single-component solutions (pH 3.5, flow rate 5 ml/min), the maximum adsorption capacity of the vermicompost for Cd (II), Cu (II), Pb (II) and Zn (II) ions were 33.01, 32.63, 92.94 and 28.43 mg/g, respectively (Matos and Arruda, 2003).

Due to its beneficial effects on plant nutrition and improvement of soil physical and chemical properties, organic matter can be used to sustainably increase crop yield (Sharifi and Renela, 2015), however, in many cases the use of this type of organic fertilizer can increase the risk of heavy metals or diseases entering the soil (Hei et al., 2016). Since heavy metals are non-biodegradable and can accumulate in living tissues, so they are concentrated throughout the food chain (Maleky et al., 2011). Toxicity of heavy metals and their risk of bioaccumulation in the food chain represents one of the environmental and health problems in today's societies (Begum and Krishna, 2010; Jamaludin and Mahmood, 2010). Earthworms are used as ecological indicators of soil pollutants due to their potential for bioaccumulation of heavy metals in their tissues (Aleagha et al., 2011). Vermicompost application not only reduces the need for chemical fertilizer in agricultural lands, but also increases plant tolerance to biological and non-biological stresses (Paol and metzger, 2005; Tenisem and et al., 2010). Adding organic fertilizer to soil contaminated with heavy metals reduced concentration of the heavy metals in the plant shoot (Singh et al., 2010). The study showed that cadmium in soil solution can bind to plant root cell walls. In fact, accumulation of cadmium in plant root is a mechanism of tolerance of high concentration of cadmium in rhizosphere of plant root (Wang et al., 2006). Studying the antagonistic effects of zinc and cadmium, it was found that zinc application could partially affect the plant's ability to absorb cadmium (Cherif et al., 2011). The heavy soils with high cation exchange capacity absorb heavy metals on the surface of negatively charged clay particles, which reduces the mobility of heavy metals in the soil compared to light soils (Owliaie and Sharifi, 2014).

The use of contaminated water for irrigation of cereal and vegetables increased their heavy metals content mostly in their root. Cu and Fe concentrations exceeded WHO standard in all parts of wheat and parsley. Zn concentration was less than the permissible limits in some of standards only in shoot of wheat. Cd concentration exceeded permissible limits in all plant parts (Mirzaei et al., 2016). According to the high risk of using contaminated water and possible contamination of the fruit and reduction of its quality, the use of vermicompost for tomato and okra under irrigation with contaminated water is not recommended. In general, the use of contaminated water is unacceptable for human and animal food (Mirzaei et al., 2019). The order of the accumulation of five metals in spinach, fenugreek and dill was Fe > Mn > Zn > Cu > Cd. The values of Fe had the highest and Cd had the lowest accumulation in plants. The concentration of Cu and Fe in the shoot and root of spinach, fenugreek and dill was higher than those recommended by the WHO standard. The amount of Zn and Mn in the shoot and root of spinach, fenugreek and dill were below the permitted limit for some standards but for others, it was more than the permitted limit. The amount of Cd in the shoot and root of the examined vegetables was higher than the permitted limit for all standards (Mirzaei and Ghamarnia, 2018). The results of the experiments showed that increased concentration of lead and cadmium in the soil, decreased the number of leaves and shoot length of ornamental sunflower while it increased the amount of lead and cadmium in the root and shoot (Mojdehi et al., 2022).

The objective of this study was to investigate the effect of vermicompost on the accumulation of copper, iron, zinc, cadmium and manganese in roots, shoots and fruits of tomato and okra plants as well as in two soil layers (0-30 and 30-60 cm).

Materials and methods

In this study, we used water from Gharesoo River for irrigation. Unfortunately, Kermanshah industrial city is not equipped with wastewater treatment system yet, consequently many industrial units such as food industries, meat products, chemical units, color production, detergent production, and metalic parts factories add their sewage into the Gharesoo River directly. Also, different types of industrial wastes, agricultural hazardous toxins, and Kermanshah natural drainage called Abshoran; full of all kinds of germs, human and industrial waste are poured directly into the Gharesoo River in different locations. Water samples were collected before the start of irrigation in May and after harvest in October and the values were averaged for the sample. Chemical properties of water were analyzed and compared to three international standards, including Food and Agriculture Organization (FAO), World Health Organization (WHO) and Environmental Protection Agency (EPA) as shown in Table 1. Accordingly, iron, copper, cadmium, manganese, selenium, nitrate, and phosphate levels exceeded the permitted level for irrigation at least for one of the standards. BOD5 and COD levels also exceeded the EPA standard. Hence, the water is not applicable to agriculture in terms of organic matter concentration and microbial quality.

Table 1. Results of chemical experiments of irrigation water and Standards

Variable	Unit	Irrigation water	International Standards		
			FAO	WHO	EPA
Hg	mg/l	0.0085			0.01
Fe	″	12.38	5	5	5
Cu	″	0.03	0.2	0.2	0.2
Zn	″	0.34	2	2	1
Cd	″	0.18	0.01	0.01	0.01
Ni	″	0.14	0.2	0.2	0.2
Cr	″	0.03	0.1	0.1	0.1
Pb	″	0.03	5	5	5
Mn	″	8.88	0.2	0.2	0.2
Co	″	0.0145	0.05		0.05
As	″	0.015	0.1	0.1	0.1
Se	″	0.065	0.02	0.02	0.02
NO_3	″	29.65	5	5	30
PO_4	″	10.97			10
BOD5	″	95			30
COD	″	192			120
SAR	-	2.08	3	3	
EC	dS/m	0.627	0.7	0.7	0.7
pH	-	7.28	6.5-8	6-8.5	6.5-8.4

We considered two treatments using vermicompost and non-use of vermicompost (control) in growing tomato and okra and two layers of soil irrigated with contaminated water in three replications at the Campus of the

Faculty of Agriculture and Natural Resources of Razi University (Figure 1). Vermicompost was applied at a rate of 25 tons/ha in two stages: at planting time 10 tons/ha and a month later another 15 tons/ha (Glick et al., 2004).

Figure 1. Location of the research project

The research was conducted in plots (1×2 m) with 0.5 m distance and three rows of cultivation in the plot. The plots were irrigated with Gharesoo River water once a week (Figure 2).

Figure 2. The treatments

Plant samples were washed with water after harvest, then were placed in the oven at 70°C for 72 hours until completely dried and finally milled. Wet digestion method was used for digestion of the samples. For each analysis 0.5 gr of the sample was accurately weighed and digested with sulfuric acid. Afterwards, the amount of copper, iron, zinc, cadmium and manganese were measured using the Spectra AA220 atomic absorption device manufactured by VARIAN factory in Australia. Also, soil samples were collected in three replications from two layers. The soil samples were air dried, ground and sieved through 2 mm sieve. The soil properties are presented in Table 2.

Table 2. Soil chemical parameters at two layers

Variable	Unit	River water	
		0-30	30-60
Na	mg/l	323 ± 86.3	302.3 ± 58.3
Ca	″	8.6 ± 1.9	13 ± 6.7
Mg	″	15.6 ± 6.6	24 ± 11.6
Cl	″	13.0 ± 3.6	23.1 ± 10.2
K	″	98 ± 5.17	94 ± 6.23
P	″	0.01 ± 0.019	0.02 ± 0.016
N	%	0.18 ± 0.03	0.15 ± 0.03
$CaCO_3$	″	8.1 ± 4.6	11.8 ± 5.6
OM	″	3.7 ± 0.5	3 ± 0.57
OC	″	2.2 ± 0.3	1.9 ± 0.3
HCO_3	mg/l	24.4 ± 13.2	18.3 ± 10.9
TDS	″	104 ± 15.8	83 ± 15.7
EC	ds/m	0.16 ± 0.02	0.13 ± 0.02
pH	-	7.1 ± 0.1	7.2 ± 0.2
SAR	-	93 ± 41	70 ± 19

The soil pH value was estimated by pH meter in the saturation extract as described by Thomas, 1996 (1:5 suspension). In the same suspension, electrical conductivity was also measured using conductivity meter. Soil organic carbon was estimated by Walkley-Black method (Walkley and Black, 1934), available phosphorous was determined by Olsen's method (Olsen et al., 1954) y using Spectrophotometer (VARIAN, Carry 100 Scan, Australia), available potassium and sodium estimated (ISRIC, 1986) using flame photometer (JENWAY, PFP7, Australia). Concentrations of soluble Ca and Mg were measured using the EDTA titration method (Schouwenburg, 1960). Cl was measured using the titration method with $AgNO_3$ (ISRIC, 1986). HCO_3^{-1} and CO_3^{-2} were measured using the titration with H_2SO_4 (ISRIC, 1986) (Figure 3).

Figure 3. Experiments

Soil texture was determined using Hydrometer 152H according to USDA and its results are shown in Table 3.

Table 3. Properties of soil texture

Layer	replication	Sand (%)	Silt (%)	Clay (%)	Texture
0-30	1	37	48	15	Loam
"	2	31	47	22	loam
"	3	29	45	26	Loam
30-60	1	45	45	10	Loam
"	2	52	30	18	Loam
"	3	41.5	40	18.5	Loam

Results and Discussion

Copper (Cu)

According to Table 4, the amount of Cu accumulation in vermicompost treatment in tomato and okra fruit increased and in okra root decreased significantly at 1% level. The results showed that vermicompost treatment reduced Cu accumulation in roots but increased its accumulation in shoot and fruit. Also, vermicompost treatment had no significant effect on Cu accumulation in soil layers, although this accumulation in both layers was higher for vermicompost treatment. Vermicompost also prevented Cu from moving deeper into the soil. Therefore, vermicompost accumulates Cu in plants and soil.

Table 4. Mean Cu of different parts of tomato, okra and soil and t-test for comparison of averages

Parameters	Part	df	Average		t-test
			V	C	(V-C)
Tomato	Root	4	0.125 ± 0.006	0.137 ± 0.007	-2.25^{ns}
	Shoot	"	0.091 ± 0.005	0.081 ± 0.004	2.7^{ns}
	Fruit	"	0.103 ± 0.005	0.069 ± 0.003	10.1^{**}
Okra	Root	"	0.06 ± 0.003	0.088 ± 0.004	-9.7^{**}
	Shoot	"	0.076 ± 0.004	0.288 ± 0.382	-0.961^{ns}
	Fruit	"	0.058 ± 0.003	0.044 ± 0.002	6.73^{**}
Soil	First Layer	"	0.462 ± 0.008	0.039 ± 0.064	1.93^{ns}
	Second Layer	"	0.478 ± 0.023	0.446 ± 0.011	2.17^{ns}

V = Vermicompost, C = Control, *Significant at 5% level, **Significant at 1% level and ^{ns} Non-significant

Past research showed that the application of vermicompost had no significant effect on Cu usability (Hosseinpur and Motaghian, 2017). It was also found that the use of bio-fertilizers prevented the movement of heavy metals in the soil (Akhzari and Khedmati, 2016) which are consistent with the results of this study. Another study showed that vermicompost reduced the amount of heavy metals in the soil, roots and stems of the ornamental sunflower plant (Mojdehi et al., 2022). The results of the above study showed that the use of compost and vermicompost increased amounts of copper accumulation in root of bean (Balouchi et al., 2019).

Iron (Fe)

According to Table 5, the use of vermicompost significantly increased Fe concentration in tomato shoots, shoots and fruit of okra at 1% level and significantly decreased Fe in tomato fruit and okra root at 1% level. The results showed that the use of vermicompost often increased the concentration of Fe in different parts of plants and soil layers compared to the control treatment. Vermicompost application also prevented the movement of Fe deeper into the soil.

Table 5. Mean Fe of different parts of tomato, okra and soil and t-test for comparison of averages

Parameters	Part	df	Average		t-test
			V	C	(V-C)
Tomato	Root	4	53.5 ± 2.68	52.6 ± 2.6	0.44^{ns}
	Shoot	"	31.85 ± 1.59	22.45 ± 1.12	8.4^{**}
	Fruit	"	2.05 ± 0.1	3.4 ± 0.17	-11.86^{**}
Okra	Root	"	14.85 ± 0.74	22.85 ± 1.14	-10.2^{**}
	Shoot	"	11.8 ± 0.59	7.9 ± 0.4	9.51^{**}
	Fruit	"	2.8 ± 0.14	1.85 ± 0.09	9.89^{**}
Soil	First Layer	"	615.4 ± 0.73	525.5 ± 108.5	1.44^{ns}
	Second Layer	"	609.8 ± 21.6	560.9 ± 35.2	2.05^{ns}

V = Vermicompost, C = Control, *Significant at 5% level, **Significant at 1% level and ^{ns} Non-significant

Studies showed that Fe concentration increased significantly with vermicompost application (Javanmard et al., 2016). Vermicompost increased the concentration of Fe in the plant (Ghasemi, 2016). The use of biofertilizers also prevented heavy metals from moving in the soil (Akhzari and Khedmati, 2016). The same results were obtained in the present study. Another study showed that vermicompost reduced the amount of heavy metals in the soil, roots and stems of the ornamental sunflower plant (Mojdehi et al., 2022). Accumulation of heavy metals in bean roots was far more than its shoots and seeds (Balouchi et al., 2019).

Zinc (Zn)

Table 6 shows that application of vermicompost significantly increased Zn concentration in shoot of tomato and okra and the first layer of soil at 1% level and significantly decreased its concentration in root and fruit of okra at 1% level. In general, vermicompost treatment increased Zn concentration in all parts of tomato, okra shoot and both layers of soil. Vermicompost application also prevented Zn movement in the soil.

Table 6. Mean Zn of different parts of tomato, okra and soil and t-test for comparison of averages

Parameters	Part	df	Average		t-test
			V	C	(V-C)
Tomato	Root	4	0.38 ± 0.019	0.38 ± 0.019	0.0^{ns}
	Shoot	"	0.239 ± 0.012	0.158 ± 0.008	9.73^{**}
	Fruit	"	0.131 ± 0.007	0.122 ± 0.006	1.7^{ns}
Okra	Root	"	0.126 ± 0.006	0.233 ± 0.012	-14^{**}
	Shoot	"	0.262 ± 0.013	0.199 ± 0.01	6.63^{**}
	Fruit	"	0.138 ± 0.007	0.185 ± 0.009	-7.18^{**}
Soil	First Layer	"	3.1 ± 0.193	1.85 ± 0.283	6.33^{**}
	Second Layer	"	2.69 ± 0.57	1.88 ± 1.61	0.824^{ns}

V = Vermicompost, C = Control, *Significant at 5% level, **Significant at 1% level and ^{ns} Non-significant

Previous research showed that the application of vermicompost had no significant effect on Zn usability (Hosseinpur and Motaghian, 2017). Studies showed that Fe concentration increased significantly with vermicompost application (Javanmard et al., 2016). Vermicompost increased the concentration of Zn in the plant (Ghasemi, 2016). The use of biofertilizers also prevented heavy metals from moving in the soil (Akhzari and Khedmati, 2016). Another study showed that vermicompost reduced the amount of heavy metals in the soil, roots and stems of the ornamental sunflower plant (Mojdehi et al., 2022). Accumulation of heavy metals in bean roots was far more than its shoots and seeds (Balouchi et al, 2019).

Cadmium (Cd)

According to Table 7, the use of vermicompost had no significant effect on Cd accumulation in different parts of tomato, okra and two layers of soil. Vermicompost treatment increased Cd concentration in the first layer and decreased it in the second layer of the soil, although the changes were not significant. Vermicompost treatment also prevented Cd from moving deeper in the soil.

Table 7. Mean Cd of different parts of tomato, okra and soil and t-test for comparison of averages

Parameters	Part	df	Average		t-test
			V	C	(V-C)
Tomato	Root	4	0.0 ± 0.0	0.0 ± 0.0	0.0^{ns}
	Shoot	"	0.0 ± 0.0	0.0 ± 0.0	0.0^{ns}
	Fruit	"	0.0 ± 0.0	0.0 ± 0.0	0.0^{ns}
Okra	Root	"	0.0 ± 0.0	0.0 ± 0.0	0.0^{ns}
	Shoot	"	0.0 ± 0.0	0.0 ± 0.0	0.0^{ns}
	Fruit	"	0.0 ± 0.0	0.0 ± 0.0	0.0^{ns}
Soil	First Layer	"	0.03 ± 0.001	0.026 ± 0.006	1.14^{ns}
	Second Layer	"	0.029 ± 0.001	0.0295 ± 0.0005	-0.775^{ns}

V = Vermicompost, C = Control, *Significant at 5% level, **Significant at 1% level and ^{ns} Non-significant

Previous studies on plants showed results different from our study. For example, increased municipal waste vermicompost application from 0 to 20 and 40 ton/ha resulted in a 1.3 and 2.4-fold reduction in soil Cd content, respectively. Also, the concentration of Cd in shoots decreased by 1.1 and 1.8 times, respectively (Baghaie and Torangzar, 2018). The results of another study showed that vermicompost significantly increased the cadmium in soil (Sharifi and Owliaie, 2014). Vermicompost mobilized heavy metals in the soil, so high levels of organic matter in the soil moved heavy metals, especially Cd, into the lower soil layers (Owliaie and Sharifi, 2014). Researchers reported increased mobility of lead and cadmium in the soil column added to the compost (inglemo et al., 2012). One study found that Cd transfer factor in the plant significantly increased with increased vermicompost content, the use of biofertilizers also prevented heavy metals from moving in the soil (Akhzari and Khedmati, 2016). Another study showed that vermicompost reduced the amount of lead and cadmium in the soil, roots and stems of the ornamental sunflower plant (Mojdehi et al., 2022). The results showed that the use of compost and vermicompost increased the amounts of cadmium accumulation in shoot and root of bean (Balouchi et al, 2019).

Manganese (Mn)

According to Table 8, the application of vermicompost significantly reduced Mn content in tomato and okra roots at 1% level, increased Mn content in tomato fruit at 1%, in tomato shoots and shoots and okra fruit at 5% level. The results showed that only the root of the tested plants experienced lower concentration of Mn but other parts of the plants showed increased Mn content. In two layers of soil, the use of vermicompost increased the accumulation of Mn, although it was not significant.

Table 8. Mean Mn of different parts of tomato, okra and soil and t-test for comparison of averages

Parameters	Part	df	Average		t-test (V-C)
			V	C	
Tomato	Root	4	1.295 ± 0.065	1.63 ± 0.082	-5.56**
	Shoot	"	1.639 ± 0.082	1.451 ± 0.073	2.97*
	Fruit	"	0.224 ± 0.011	0.175 ± 0.11	5.97**
Okra	Root	"	0.279 ± 0.014	0.374 ± 0.018	-7.12**
	Shoot	"	1.43 ± 0.072	1.23 ± 0.061	3.84*
	Fruit	"	0.388 ± 0.019	0.343 ± 0.017	3.06*
Soil	First Layer	"	28.43 ± 2.08	25.98 ± 2.68	1.25 ns
	Second Layer	"	39.33 ± 7.33	35.9 ± 5.8	0.635ns

V = Vermicompost, C = Control, *Significant at 5% level, **Significant at 1% level and ns Non-significant

Studies showed that Mn concentration increased significantly with vermicompost application (Javanmard et al., 2016). Another study showed that vermicompost reduced the amount of heavy metal in the soil, roots and stems of the ornamental sunflower plant (Mojdehi et al., 2022). Accumulation of heavy metals in bean roots was far more than its shoots and seeds (Balouchi et al, 2019).

Conclusions

Results showed, Cu and Mn increased in tomato fruit and Fe decreased significantly in tomato shoot. We detected a significant decrease in Mn only for tomato root. Also, Cu, Fe and Mn increased and Zn decreased significantly in okra fruit, while in okra shoot, Fe, Zn and Mn increased significantly whereas in the root Cu, Fe, Zn and Mn decreased significantly. Therefore, it can be concluded that the use of vermicompost in most parts of tomato and okra significantly increased the concentration of metals. Although vermicompost treatment increased the accumulation of these metals in soil, this increase was not significant, and only in the first layer we witnessed a significant increase in Zn. Another result is that vermicompost prevented the movement of metals deeper into the soil. Therefore, the use of vermicompost and irrigation with contaminated water is not recommended due to the increase in heavy metals content in different parts of the studied plants and soil.

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