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EVALUATING THE EFFECTS OF MUNICIPAL WASTE AND WASTEWATER ON ABSORPTION OF NICKEL AND CADMIUM OF HELIANTHUS ANNUUS PLANT

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Abstract

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The present study is an attempt to examine the effects of municipal waste and wastewater on absorption of nickel and cadmium of helianthus annuus plant. In order to determine cadmium and nickel in different organs of the plant in soil with organic fertilizers of municipal waste and municipal sewage sludge, we conducted a split plot study. The study was in form of randomized complete block from 2011 to 2015 under farm conditions. We considered the main factor in five levels of control, 10 and 20 tons of sewage sludge and municipal waste compost per hectare besides the minor factor of yearly treatment during four years. The results showed that using 20 tons of sewage sludge and waste per hectare increased absorbable soil nickel and cadmium up to approximately 220%. Also, the amount of cadmium and nickel in root was about 400% more than the control group. Bacteria found in soil contaminated to heavy metals showed remarkable resistance against higher concentration of these elements. Both bioaccumulation and biosorption techniques indicated high potential to refine aquatic environments. However, the bioaccumulation technique showed better efficiency in lower concentrations and the biosorption revealed better efficiency in higher concentrations of metals.

Keywords: helianthus annuus, waste sludge, municipal waste compost, cadmium, nickel

INTRODUCTION

One of the most important global issues is environmental pollution with toxic and dangerous heavy metals (Chong, Wong, Tam, 2000; Liehr, Chen, Lin, 1994; Matheical, Yu, 1996). Mining and extensive use of heavy metals in industries have led to increased concentration of these metals in water, air and soil to values more than underlying values (Volesky, B., 1990). The mechanism of the toxic effects of heavy metals is due to strong tendency of these metals cations to sulfur ions and thereby disrupting the activity of critical enzymes in living organisms (Baird, 1999; Gupta, Shrivastava, Jain, 2001). In addition to toxicity of these metals, their accumulation properties in living organisms have added to their sanitary importance. The conventional methods for removing heavy metals from wastewater are chemical deposition in form of hydroxide, sulphide and ion exchange. But, these methods are very expensive hindering the industry men from using such techniques. Also, these methods cause sludge produced after chemical deposition. The problem in aquatic environments has created new problems in waste, which is not compatible with the environment (Gadd, Griffiths, 1978; Volesky, 1987; Volesky, 1990). Such problems have made the biological removal as a good choice either economically or environmentally (Tung, Lawson, Prince, 1988).

Biosoprtion is the process of physic-chemical absorption of heavy metals by non-living micro-organisms, which depend upon specific molecular structure of cell wall [4]. Contrarily, bioaccumulation consists of active removal dependent upon heavy metals metabolism in resistant micro-organisms and so is able to accumulate them [4]. Active absorption of heavy metals by micro-organisms is strictly sensitive to environmental conditions like temperature, pH, etc. moreover, bioaccumulation requires nutrient to survive. Active absorption besides heavy metals capacity by micro-organisms is slight. As a result, bioaccumulation shows a small capacity to compete with common technologies of heavy metals removal from aquatic environments (Wase, Forster, 1997). Therefore, for effective heavy metals removal from water and wastewater need for more developed and economic methods. To this end, several different studies have been conducted on biosorption technique.

In the recent years, heavy metal absorption by other organic masses like sawdust, bran, fruit leaves, bark and so forth, is also called biosorption. The previously performed studies on the biosorption have revealed that some organic masses have high heavy metals absorption. So that, they compete with the conventional industries of wastewater heavy metals removals. Entering these organic masses into industry would result in manufacturing some commercialized products, which could be extensively used in wastewater heavy metals removal. Proven biological mechanisms involved in the biosorption process include complex with cell surface and surface absorption, ion exchange, chelatation, micropoecipitation, and oxadiation and reduction reactions. According to the type of biological absorbent several different mechanisms are involved in the biosorption process of metals removal (Gupta, Ahuja, Khan, Saxena, Mohapatra, 2000; Volesky, 2001; Gadd, 1990). Numerous studies have investigated the biosportion process of heavy metals of treatment plant sludge including activated sludge, fecal sludge, and aerobic and anaerobic granular. Due to heterogeneous microorganism heterogeneous masses and microbial consortium, sewage sludge could be considered as a suitable biomass for biosorption studies (Norton, Baskaran, McKenzie, 2004).

In the recent years a large body of research has worked on the biosportion process of heavy metals by biological absorbents like a variety of fungi species, algae, bacteria, aerobic sludge yeast. Also, biological additions and fluids such as fruits skins and so forth have been taken into account. Meanwhile, a considerable portion of studies has investigated algae and fungi and a minor portion has studied sludge. Tabs. I and II illustrate the results. As it can be seen, few studies have worked on metals uptake through biosolids. To name, Norton et al investigated zinc uptake through biosolids. Thy reported the zinc uptake 0.564 mmol/g. No study investigated Nickel and cadmium uptake by this absorbent. Accordingly, the present research examined nickel and cadmium uptake from aquatic solution by sewage sludge and wastes produced by municipal waste treatment. Tab. I shows the results.

METHOD

For examining cadmium and nickel in different organs of plant in addition to using different organic sludge fertilizers and municipal waste compost, we conducted a split-plot study in form of randomized block plan in farm conditions from 2011 to 2015. We measured the major factor in the five levels of control, 10 and 20 tons of sewage sludge and municipal wastewater compost per hectare. The minor factor was annual treatments in four years. We tested the impact of flooding, wastewater and sewage sludge and waste on cadmium and nickel absorption and concentration in root, stems and shoots Helianthus annuus L. the test was in form of factorial experiment and in form a completely randomized design with three replications including a 4-year period, in 10 and 20 tons per hectare volumes. We extracted the soil from the Khalatposuhan Research Center in farm conditions. The soil was taken from 0–20 cm depth. The organic fertilizers used in the present research were sewage sludge produced by treatment plant in Miyaneh. Also, we prepared manure from Khalatposuhan agricultural Research Center at Agriculture School of Tabriz University. At the end of growth period, aerial parts were taken from crown section. Then, roots were separated from soil. After washing with distilled water, the root and aerial parts were put into plant drier at 70° Celsius for 72 h. Next, using a plastic mill, glass lid and aluminum blades were powered and got stiffed by a 1mm stiffer. In the next stage, we measured nickel and cadmium concentration in the root and aerial parts through dry burning (Westerman, 1990) and via atomic absorption spectrophotometer model AA-6200 manufactured by Shimadzu Japan.

We calculated each metal uptake by multiplying the element concentration in dry material of aerial and root parts. The transfer factor was computed via dividing the metal concentration in the aerial part over the concentration in the root. This factor is an indicator for determination of the plant ability in transferring metals from root to aerial parts. If the factor value is greater than 1, this shows that the plant accumulates metal in aerial parts. While, if the value smaller than 1, the plant does no accumulate metal in root and so the circumstances are inappropriate for phytoremediation through metal extraction from growth base and refining the base from the metal contamination (Yoon, Cao, Zho and Ma, 2006; Das and Maiti, 2007).

FINDINGS

Atomic absorption spectrometry analyses of heavy metals in soil mixed with sewage sludge indicated the relatively high concentrations of these elements in soil. Zinc and iron showed the highest frequency with 29.4 and 24.475 mg/kg concentration. Cadmium and nickel concentration were 0.087 and 0.88 mg/kg, respectively. Considering morphological characteristics, biochemical tests belonged

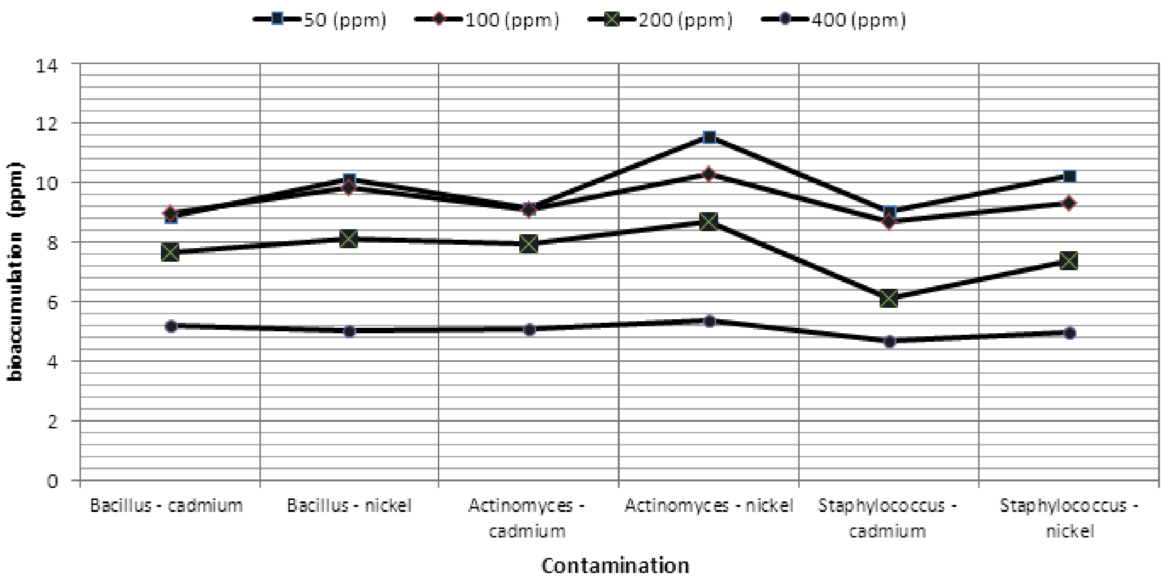
I: *The results of different studies on biosorption of nickel and cadmium by different biomasses*

Reference	Absorption capacity mmol/g	Metal ion	Status	Genus and species	Biomass type
Davis, T. A., Volesky, B., Mucci, A., 2003	1.705	cadmium	Living	Funalia trogii	fungi
Liu, Y., Yang, S. F., Xu, H., Woon, K. H., Lin, Y. M., Tay, J. H., 2003	1.536	cadmium	Living	Aerobic granules	algae
Arıca, M. Y., Lu, G. B., Yilmaz, M., Bekta, S., Genç, Ö., 2004	1.466	cadmium	Non-living	Funalia trogii	fungi
Yalçinkaya, Y., Soysal, L., Denizli, A., Arica, M. Y., Bekta, S., Genç, Ö., 2002	1.361	cadmium	Non-living	Trametes versicolor	fungi
Yu, Q., Matheickal, J.T., Yin, P., Kaewsarn, P., 1999	1.18	cadmium	Non-living	Durvillaea potatorum	algae
Holan, Z. R., Volesky, B., Prasetyo, I., 1993	1.17	cadmium	Non-living	Sargassum natans	algae
Eaton, A. D., Clesceri, L., Greenbery, A. E., 1998	1.16	cadmium	Non-living	Lessonia avicans	algae
Liu, H. L., Chen, B. Y., Lan, Y. W. and Cheng, Y. C., 2004	1.15	cadmium	Non-living	Ecklonia maxima	algae
Holan, Z. R., Volesky, B., Prasetyo, I., 1993	1.12	cadmium	Non-living	Durvillaea potatorum	algae
AWWA, 1990	1.11	cadmium	Non-living	Laminaria japonica	algae
Liu, H. L., Chen, B. Y., Lan, Y. W. and Cheng, Y. C., 2004	1.103	cadmium	living	Trametes versicolor	fungi
Matheickal, J. T., Yu, Q., Woodburn, G. M., 1999	1.1	cadmium	Non-living	Durvillaea potatorum	algae
AWWA, 1990	1.10	cadmium	Non-living	Lessonia nigresense	algae
Cruz, C. C. V., Carlos, A., da Costa, A., Henriques, C. A., Luna, A. S., 2004	1.0676	cadmium	Non-living	Sargassum sp	algae
Yu, Q., Matheickal, J. T., Yin, P., Kaewsarn, P., 1999	1.04	cadmium	Non-living	Ecklonia radiata	algae
Inthorn, D. *et al.* 2002	0.979	cadmium	Non-living	Scenedesmus acutus IFRPD 1020	algae
Dilek, F. B., Erbay, A., Yetis, U., 2002	0.971	nickel	Non-living	Polyporous versicolor	fungi
Deng, S., Ting, Y. P., 2005	0.937	nickel	Non-living	Penicillium chrysogenum	fungi
Yu, Q., Matheickal, J.T., Yin, P., Kaewsarn, P., 1999	0.93	cadmium	Non-living	Ascophyllum nodosum	algae
Kacar, Y., Arpa, C., Sema Tan, S., Adil Denizli, A., Genc, O., Arica, M. Y., 1999	0.874	cadmium	Non-living	Phanerochaete Chryosporium	fungi
Yu, Q., Matheickal, J. T., Yin, P., Kaewsarn, P., 1999	0.82	cadmium	Non-living	Laminaria hyperbola	algae
Aksu, Z., 2002	0.819	nickel	Non-living	Chlorella vulgaris	algae
Inthorn, D. *et al.*, 2002	0.801	cadmium	Non-living	Tolypothrix tenuis TISRT 8063	algae
Davis, T. A., Volesky, B., Vieira, RHSF., 2000	0.79	cadmium	Non-living	Sargassum vulgare	algae
Özer, A., Özer, D., 2003	0.7886	nickel	Non-living	Saccharomyces cerevisiae	fungi
Aksu, Z., 2001	0.759	cadmium	Non-living	C. vulgaris	algae
Holan, Z. R., Volesky, B., 1994	0.75	nickel	Non-living	Sargassum fluitans	algae
Hashim, M. A., Chu, K. H., 2004	0.74	cadmium	Non-living	Sargassum baccularia	algae
Davis, T. A., Volesky, B., Vieira, RHSF., 2000	0.71	cadmium	Non-living	Sargassum fluitans	algae

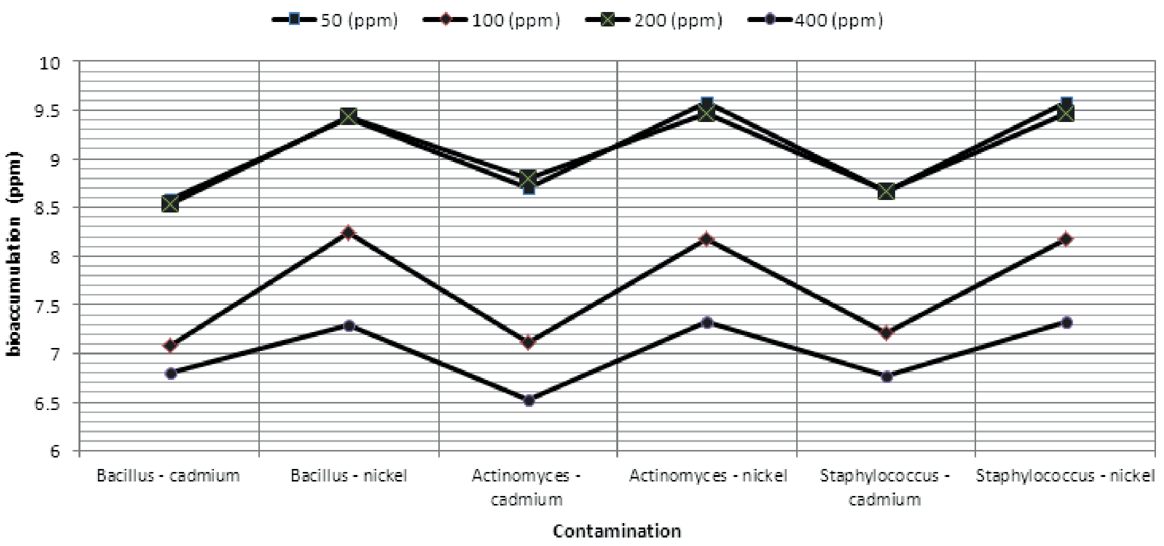
to Bacillus, Staphylococcus, and Actinomyces species after using the instruction of leaves classification of isolated bacteria. The minimum inhibitory concentration of nickel in all three species was greater than cadmium. Figs. 1 and 2 illustrate the results of ANOVA for biosoprtion and

II: *Some chemical characteristics of waste and sewage sludge*

Lead	Cadmium	Zinc	Nickel	Manganese	Iron	Phosphorus	Potassium	Sodium	$Ec_{[1:2]}$ [Ds/M]	$Ph_{[1:2]}$	
14.2	0.87	28.4	44.77	26.66	32.37	188.4	1612.1	675.9	4.1	6.17	Sewage sludge Mg/kg



1: *Bioaccumulation*

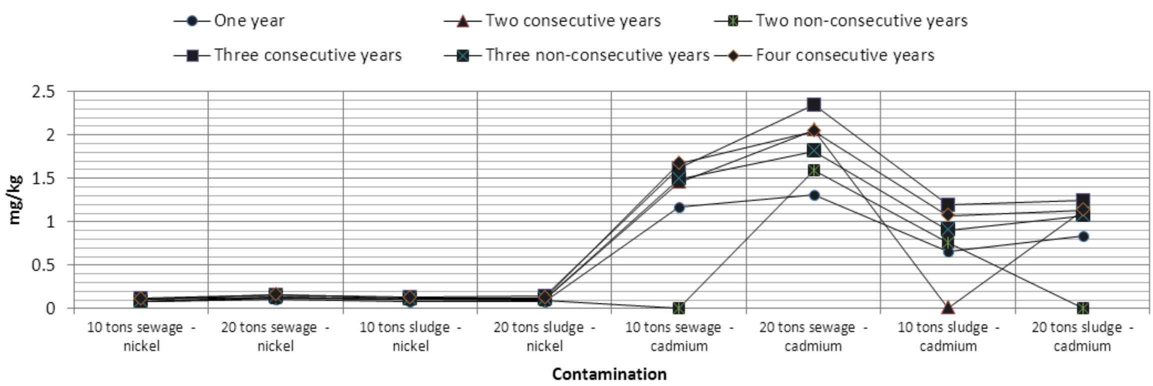


2: *Biosorption*

bioaccumulation by bacteria in different levels of cadmium and nickel in addition to mutual effects of different treatments. The results of nickel and cadmium bioaccumulation by the bacteria indicated that Actinomyces has more ability to accumulate nickel and cadmium considerably more than the other two bacteria. The bioaccumulation sequence of nickel and cadmium by bacteria was:

Bacillus < *Staphylococcus* < *Actinomyces*.

The variance between bioaccumulation value of nickel and cadmium in three bacteria was statistically meaningful in 1% level of significance. Also, in all the bacteria treatments, by an increase in the heavy metals concentration, bioaccumulation value increased, as well. The maximum and minimum bioaccumulation values of nickel and cadmium in the three bacteria were 400 ppm in contamination level 50. The maximum cadmium and nickel accumulation of all bacteria was in



3: *Cadmium and nickel in stem*

contamination level 50 ppm. So that, after an increased in the elements consternation, in spite of increased bioaccumulation value, bioaccumulation percentage decreased. Fig. 1 shows bioaccumulation and Fig. 2 shows biosorption.

Cadmium and Nickel in Stem

The ANOVA results showed that using sewage sludge and municipal compost has a statistically meaningful impact on cadmium and nickel absorption of soil. Employing 20 tons of sewage sludge per hectare during three non-consecutive years and four consecutive years, the maximum cadmium uptake was 0.16 mg/kg. Also, using 20 tons of sewage sludge per hectare in three non-consecutive years indicated the maximum nickel uptake 2.35 mg/kg. Increased amount of these metals after using sewage sludge could result from increased amount of organic materials in soil because of higher degrees of sewage sludge. Consequently, because of this increase, metals make a volatile link with organic compounds and are easily converted into soluble form (Antoniadis and Alloway, 2002). Ortiz and Alkaniz realized that presence of organic materials adds to the rate of soluble metals in soil (Ortiz and Alkaniz, 2006). Using two different types of 10 and 20 ton per hectare municipal compost showed slight increase in cadmium and nickel uptake compared with sewage sludge treatments.

But, we should note that two treatment levels of municipal compost significantly increased cadmium absorption compared with the control treatment except for a one- year period. After treating 20 tons of sewage sludge resulting to the maximum soluble nickel in soil, using 10 tons of sewage sludge per hectare increases soluble nickel compared with 10 and 20 ton treatment of municipal compost. Bahrehmand et al and Rezaeinejad and Afyouni studies indicated that using organic and non-organic fertilizers increase nickel and cadmium uptake in soil (Bahremand, Afyuni, Haj Abbasi and Rezaie Nejad, 2002; Rezaie Nejad and Afyuni, 1999; Jordao, Cecon and Pereira, 2003). A few other researchers also believe that organic fertilizers (e.g. sewage sludge and municipal waste compost) are the most important resources of heavy elements like cadmium and nickel in soil.

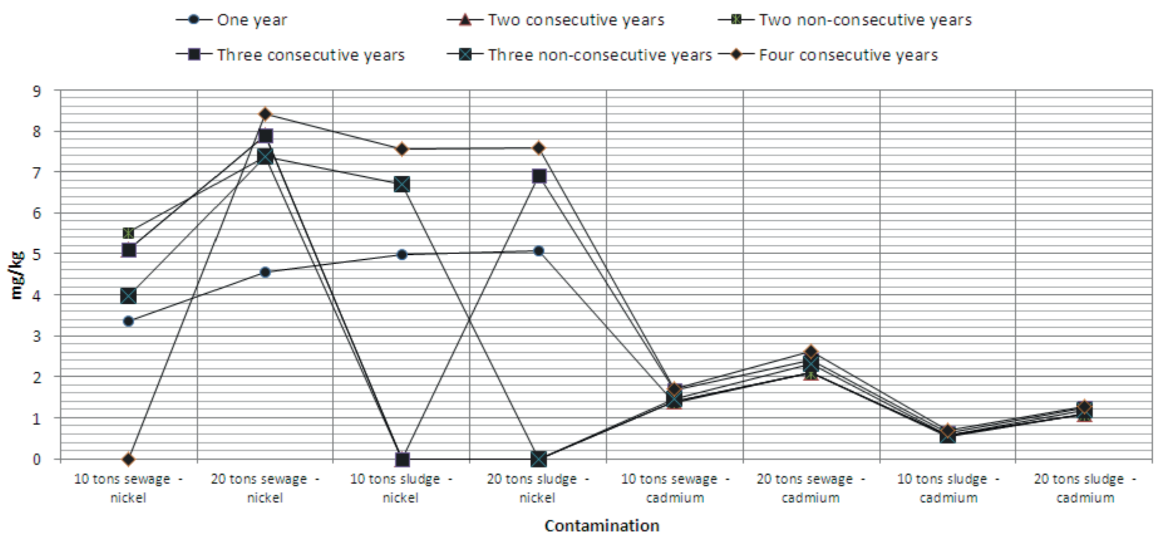
Fig. 3 shows cadmium and nickel in stem.

Long-term use of organic wastes such as sewage sludge and municipal waste compost have led to increased absorbable form of cadmium and nickel in comparison with the control group. In the treatments of the year, the consumption of these wastes in form of non-consecutive years and using during four consecutive years increased absorbable cadmium and nickel in soil. However, in some cases this increase was statistically insignificant compared with the control group. Some scholars believe that accessibility to heavy metals is in its maximum level during the initial three to four years after using sewage sludge. But, in the following years this trend continues in form of lower accessibility, yet more sustainability of metals in soil (Rundle, Calcroff and Hoh, 1982).

Single or repeated application of organic fertilizer contaminated with metals can lead to increased accessibility of metals or changes in the forms of metals in large quantities. This is due to analysis of poorly soluble forms which initially exist in sludge like sulfites or the organic compounds (McBride, 2003). Moreover, the results showed that using sewage sludge per hectare in 2006 and a delay in using them during the coming years (after four years) revealed a statistically meaningful increase in cadmium, 40 tons of sewage sludge per hectare treatment. The same result was observed about nickel. The 20 and 40 ton sewage sludge treatments indicated a statistically significant increase which shows the residual effects of these metals (Bevacqua and Mellano, 1993).

Cadmium and Nickel in Roots

Different fertilizer treatments showed a statistically meaningful effect on cadmium in roots. The results of fertilizer treatments indicated that 20 ton sewage sludge treatment caused the maximum cadmium accumulation amount, 2.62 mg/kg in roots. Also, 10 ton sewage sludge treatment accumulated more cadmium compared with 20 ton municipal sewage compost treatment. In this regard, 10 ton municipal sewage compost



4: *Cadmium and nickel in roots*

treatment led to a statistically meaningful increase in roots cadmium versus the control treatment. A few other scholars have reported heavy metals accumulation after using organic materials. The minimum accumulation belonged to 10 ton municipal sewage compost treatment. We observed the maximum amount of nickel 8.42 mg/kg in roots in 20 ton sewage sludge treatment. This result accords with the previously performed studies (Pais and Jones, 1997; Skousen and Clinger, 1991).

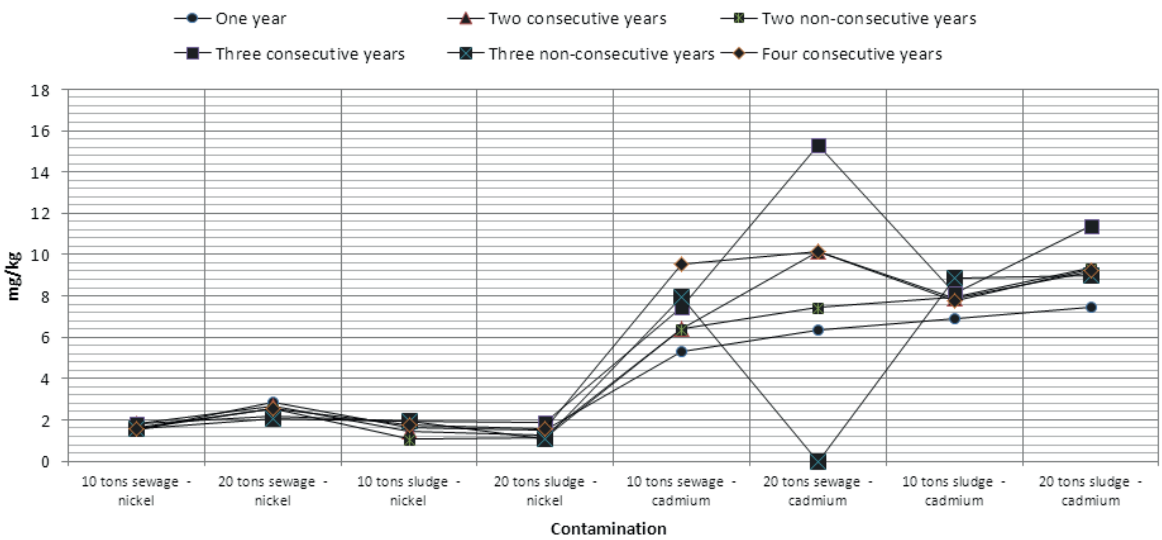
The 10 and 20 ton municipal waste sludge treatment had no significance difference, but they indicated a statistically meaningful increase compared with the control treatment .comparing the treatments average during the study years indicated that employing organic fertilizers for four years created the maximum increased possible cadmium. But, using organic fertilizers in non-consecutive and four consecutive years increased nickel in roots. The existing pool of research has reported that increased employment of organic fertilizers in the recent years has raised absorption of metals in plants (McBride, 1995). Consuming sewage sludge and municipal waste compost in three non-consecutive years besides a four-consecutive year treatment increased cadmium in roots. This confirms the accumulative effects of organic fertilizers on greater cadmium accumulation in roots.

Measuring the amount of nickel in roots in different periods revealed that using a two and three non-consecutive and two and three consecutive treatments of organic fertilizers had no different compared with each other. That is to say, consuming organic fertilizers within different years except for four consecutive years had no statistically significant effect on the rate of nick absorption in roots. However, for the control treatment consuming organic fertilizers showed a meaningful effect and nickel increased in roots. It should be noted here that after four years of consuming organic fertilizers, the one-year treatment showed a statistically meaningful increase in roots accumulated nickel and cadmium for all the used treatments. However, for the 10 tons of sewage sludge per hectare of nickel and 20 tons of municipal waste compost per hectare of cadmium the increase was insignificant in comparison with the control group. This result indicates the residual effects of consumed organic fertilizers.

Fig. 4 shows cadmium and nickel in roots.

Cadmium and Nickel in Leaves

Considering the ANOVA results, cadmium and nickel absorption in leaves during different fertilizer treatments was statistically meaningful. The maximum cadmium in leaves was 2.13 mg/ kg in 20 ton of sewage sludge treatment. Also, 10 ton sewage sludge per hectare treatment increased cadmium in leaves more than 20 ton municipal waste compost per hectare treatment. Likewise, 20 ton municipal waste compost per hectare treatment added to leaves cadmium greater than 10 ton municipal waste compost per hectare treatment. Examining the amount of nickel in leaves indicated that during 20 ton sewage sludge per hectare treatment used in three non-consecutive years, the maximum accumulated amount of nickel was 15.32 mg/kg in leaves. This result was in accordance with the former studies (Kovacik, Tomko, Backor and Repca, 2006). The 20 ton municipal waste compost created the maximum amount of nickel in leaves after the 10 ton sewage sludge treatment. On the other hand, the 10 tons per hectare of organic fertilizers treatment showed the minimum accumulated amount of nickel in leaves. However, these treatments had a statistically meaningful variance with the control group. In each column and row numbers with at least one common letter in 5% level of Duncan test have no statistically meaningful difference.



5: *Cadmium and nickel in leaves*

Analyzing different periods of using organic fertilizers showed no statistically meaningful effect on leaves cadmium. But, in three non-consecutive year treatment, the maximum nickel uptake of leaves was 15.32 mg/kg, which was three times more than the control group. We observed accumulative and residual effects of organic fertilizers consumption in leaves accumulated nickel indicating the high environmental risks of using these fertilizers in cultivation soil.

Fig. 5 shows cadmium and nickel in leaves.

CONCLUSION

Although consuming sewage sludge and municipal waste compost positively affected the plant growth, the amount of absorbable nickel and cadmium in soil, root, leaves and flower increased, as well. By increase in frequency of annual fertilizing, absorption and accumulation of cadmium and nickel increased in root, leaves and flower. Using 20 tons of sewage sludge and municipal waste compost during three non-consecutive years and four consecutive years showed the maximum accumulation in different organs. In the treatment in which organic fertilizers were consumed for one year only, the minimum possible amount of nickel and cadmium was accumulated in soil and the plant organs. Yet, because of residual effects of elements the treatment indicated a statistically significant difference with the control treatment.

The cadmium and nickel transfer coefficients indicated the accumulation of the elements in aerial parts, but the accumulation coefficient varied for the both elements. The root absorbed more soil cadmium than nickel, and the root cadmium was greater. So, making an interval between fertilizing frequency could be useful in reducing absorption rate. Although, accumulated amount of cadmium and nickel is not critical, the growth of herbs consumptions in Iran requires more strict attention to long –time use of sewage sludge and municipal waste compost.

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