African Journal of Agricultural Research Vol. 6(16), pp. 3740-3746, 18 August, 2011
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR10.813
ISSN 1991-637X ©2011 Academic Journals

Full Length Research Paper

Change of pH, organic carbon (OC), electrical conductivity (EC), nickel (Ni) and chrome (Cr) in soil and concentration of Ni and Cr in radish and lettuce plants as influenced by three year application of municipal compost

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Accepted 11 July, 2011

In order to investigate the effects of applying municipal solid waste (MSW) on the amount of pH, organic carbon (OC), electrical conductivity (EC), nickel (Ni) and chrome (Cr) in soil, as well as the concentration of Ni and Cr in lettuce and radish plants, a field experiment was conducted as split-plot arrangement based on randomized complete block design with three replications in 2008. The main plot was municipal solid waste added to the soil in three levels (0, 20 and 40 ton ha^{-1}) and the sub-plots were applied in 3 years, which comprised 2006, 2006-2007 and 2006-2008. The results showed that application of MSW in three years had significant effect on the amount of pH, OC, EC, Ni and Cr in soil (available and total) and plant organs (root and shoot). Application of 40 tons MSW ha^{-1} in three continuous years decreased the amount of pH and increased the amount of OC and EC in soil. The maximum amount of lead (Pb) and cadmium (Cd) (total and available) was accumulated in 40 ton ha^{-1} treatment, but the application of MSW in one-year and two-year treatments produced significantly different results compared to the control treatment. Three-years application (cumulative effect) at all levels of MSW increased the concentrations of available and total Ni and Cr in soil significantly. The amount of Ni and Cr in roots and shoots of lettuce and radish were increased in 40 ton.ha^{-1} treatment for three years and this increase was observed in treatments that received MSW in one or two years.

Key words: Municipal solid waste, nickel (available and total), chrome (available and total), lettuce and radish.

INTRODUCTION

The compost quality is the most essential criterion in recycling organic waste, as well as its marketing and utilization in agriculture as organic amendments. The great amount of organic matter and mineral components that are contained in biowastes (municipal solid waste, sewage sludge, manures, etc.) allows its application for crop production and soil reclamation, after a proper stabilization process (Kidd et al., 2007). Some studies have been conducted in African semi-arid climates showing soil chemical properties' improvement under municipal solid waste compost (MSWC) treatment (Oue´draogo et al., 2001). After the pH, the presence of organic matter is the most important indicator of the soil quality. Organic matter indeed covers the major reserves of nutritive substances for plants (Rattan et al., 2005). Mohammadinia (2008) by applying municipal solid wastes in rice cultivation concluded that because of mineral and organic acids, compost have as acidity and decrease pH of soil. In a one- year research done at Esfahan university of Iran, it became known that adding municipal solid wastes to the soil increases the organic

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Abbreviations: MSW, Municipal solid waste; **Ni,** nickel; **Cr,** chrome; **DTPA,** diethylenetriamine pentaacetic acid; **EC,** electrical conductivity; **OC,** organic carbon.

Table 1. Some physiochemical properties of studied soil (0-30 cm) and municipal solid waste.

Property	Soil	MSW
Soil texture	Silty loam	-
pH	7.7	8.3
EC (dS/m)	0.69	2.5
OC(%)	2.14	11.3
Nickel (total) (ppm)	41.85	47.51
Nickel (available) (ppm)	0.85	6.10
Chrome (total) (ppm)	28.53	92.13
Chrome (available) (ppm)	0.02	2.30

material of soil, especially in soils with low organic material (Rahimi, 1988).

The fate of metals upon the supply of organic matter to a soil is unsure. On the other hand, an increase of the organic matter content encourages the fixation of heavy metals in soils by the formation of insoluble organometallic complexes and therefore, it decreases their mobility and phytotoxicity (Udom et al., 2004). Smith et al. (1996) have also mentioned that the soil salinity increases as a result of annual application of compost and considered it as a limiting factor regarding its application in farm lands. Heavy metals are one of the main and most important pollutants and a serious danger for living creatures (Rooney et al., 2007). However, the repeated application of compost can generate the accumulation of heavy metals in soils (Iwegbue et al., 2007; Qiao et al., 2003; Kidd et al., 2007). These elements can be assimilated by plants, and thus contaminate the food chain and threaten human health (Smolders et al., 2004; Jordao et al., 2006). They could hamper the use of municipal solid waste composts in agriculture. The concentration of heavy metals in municipal solid waste composts is related to the quality and the original composition of the waste materials used for composting, site characteristics and techniques applied for composting (Smith, 1996). Increasing metal concentrations and changes in the distribution of metals in soil amended with compost in the long-term are generally reported to increase the concentrations of heavy metals in the tissues of plants growing in the soil (Zheljazkov and Warman, 2004b; Wei and Liu, 2005). Compost and sewage sludge additions to agricultural and other non-metal contaminated soils raise the soil content and the availability of heavy metals for transfer to crop plants. The availability in the soil depends on the nature of the chemical association between a metal with the organic residual and soil matrix, the pH value of the soil, the concentration of the element in the compost and the soil, and the ability of the plant to regulate uptake of a particular element. The main objective of the present study is to investigate the effects of applying municipal solid waste on some soil chemical properties and accumulation of Ni and Cr in soils and lettuce and radishes plants.

MATERIALS AND METHODS

This project was performed during 2006-2008 cropping season in the research field of Sari Agricultural Sciences and Natural Resources University, Sari, Iran. This area is located in the North of Iran (34° 33"N; 52° 6'E and altitude 16 m). A field experiment was carried out as split-plot arrangement based on randomized complete block design with three replications in 2008. The main plot was MSW added to soil in 3 levels (MSW_0, MSW_{20} and MSW_{40} ton.ha^{-1}). Application years considered as sub-plots comprised 2006, 2006+2007 and 2006-2008. This investigation started in plots with size of 3 × 12 m, since 2006. The fertilizer treatments were added to the soil in 2007, to 2/3 of the initial plots, (3 × 8 m) and in 2008 to 1/3 of the initial plots, (3 × 4 m). Before planting in 2006, soil samples were taken to determine some chemical properties of soil. Some properties of soil and municipal solid waste are shown in Table 1. Soil texture (Westman, 1990), organic matter (Nelson, 1982), pH and electrical conductivity (EC) (Nelson, 1982), were also determined. Furthermore, the available Ni and Cr were determined in diethylenetriamine pentaacetic acid (DTPA), extract (Lindsay and Norvell, 1978). The soil samples were extracted with hydrochloric acid (HCL) and nitric acid (HNO_3) and total heavy metals were determined with atomic absorption spectrometry (Baker and Amacher, 1982). At harvest stage, the roots and shoots of Lettuce and radish were sampled. Dry ash was utilized to determine the content of Ni and Cr in the roots and shoots (AOAC, 1990).

RESULTS AND DISCUSSION

pH, organic carbon (OC) and electrical conductivity (EC) in soil

Variance analysis (presented in Table 2) showed that different levels of municipal solid waste had no significant effect on soil pH. But its application for 3 continuous years and the effect of municipal solid waste x application years showed a significant effect on soil pH. Control treatment had the highest pH and MSW_{40} in 3-years (with 2.25% decrease compared with control) had the lowest pH (Table 3). Treatments with one year of municipal solid waste application had a significant difference with control. They showed a significant difference with other municipal solid waste-application levels (Table 3). But in application

Table 2. Analysis of variance of soil properties.

Parameter	pH	OC	EC	T- Ni	A -Ni	T- Cr	A- Cr
MSW	ns	ns	*	**	**	**	*
Application years	**	**	**	**	**	**	**
MSW years Application	*	*	**	**	**	**	*

T, Total; A, available; *, ** and ns, significant in 5%, 1% levels and no significant, respectively (based on Duncan test).

Table 3. Means comparison interaction effects of MSW x application years on pH, OC and EC in Soil.

Treatment	pH			OC (%)			$EC(ds.m^{-1})$		
	A	B	C	A	B	C	A	B	C
control	7.71^{a}	7.70^{a}	7.70^{a}	2.14^{b}	2.13^{b}	2.13^{b}	0.69^{c}	0.67^{c}	0.66^{c}
MSW_{20}	7.55^{c}	7.68^{ab}	7.65^{b}	2.04^{b}	2.25^{b}	3.02^{a}	0.87^{bc}	0.89^{bc}	1.39^{a}
MSW_{40}	7.53^{c}	7.70^{a}	7.70^{a}	2.18^{b}	2.48^{b}	3.04^{a}	0.97^{b}	1.03^{b}	1.50^{a}

A, 2006; B, 2006 -2007; C. 2006-2008. Means within the same column and row in each factor followed by the same letter are not significantly different according to DMRT ($p<0.05$).

of two-years, with the increase of municipal solid waste level, none of the application levels showed a significant difference with control treatment (Table 3). Therefore, it seems that MSW decreases soil pH at a few levels. Rose (1994) reported that soil pH decreases by adding municipal solid waste. It seems that soil pH decreases by adding municipal solid waste, because it increases organic and material acids such as: lactic acid, acetic acid and amino acids (Louisa, 2006).

There was no significant relation between municipal solid waste and organic carbon of the soil. But there was a significant relation between municipal solid waste and years of application, regarding its effect on organic carbon of the soil (Table 2). The lowest amount of organic carbon in soil (2.04%) is seen in one-year application of MSW_{20} and the highest amount (3.04%) is seen in 3-years application of MSW_{40}. Also, there was no difference between control treatment and one-year application of municipal solid waste. But increase of municipal solid waste application caused a significant difference in other treatments compared with control treatment. Therefore, organic carbon increased with the increase of municipal solid waste application. In fact, a part of active carbon of organic municipal solid wastes has been decomposed after entering the soil. Also, a part of municipal solid waste carbon has been added to carbon reserve in soil and increase the level of soil organic material (Delas et al., 2005).

This result is consistent with the Maynards (1995) findings who used 50 ton/acre of municipal solid waste for 3 years and observed that the level of organic material of soil increased from 4.3 to 8.15%. Meanwhile, Burruzini and Delzan (1992) observed a significant increase in organic carbon of soil in a 5-year application of municipal solid waste and animal fertilizers. Moreover, the increase of the organic matter content in the soils was proportional to the application rates. This was previously also observed by Mohammad and Athamneh (2004), Mendoza et al. (2006) and De Las Heras et al. (2005). In the same field as the present study, Bouzaiane et al. (2007) noted a noticeable increase in soil organic matter and microbial biomass in municipal solid waste treated plots after three years. Municipal solid waste, application years and interaction effect of MSW x application years had significant effect on EC amount (Table 2). Application of municipal solid waste increased soil EC too (Table 3).

The one-year fertilization showed that the remained fertilizers had a significant difference with control treatment only at MSW_{40}. By the increase of MSW, soil EC increased significantly. The highest amount of EC (1.50 $ds.m^{-1}$) was seen in application of MSW_{40} for 3 continuous years. It showed more than 100% of increase compared with control treatment. The lowest EC was seen in control treatments. Zhe et al. (2004) also declared that application of organic material increases soil EC. They attributed this increase to the salts solved in these fertilizers. The present study gives support to this finding. Studies showed that salts containing sodium and potassium have high solubility and the capacity to be quickly separated from municipal solid waste mass. This increases the electrical conductivity of soil solution in a short time after application of these compounds (Iwegbue et al., 2007). Also, Smith et al. (1996) mentioned increase of soil salinity as a result of annual application of municipal solid waste as a factor which limits reported application of municipal solid wastes in farm lands. Ramos (2005) stated that the application of MSW during 2-year in highly calcareous soil was responsible for slight increase of the electrical conductivity. Walker et al. (2004) explained the increase of the electrical conductivity in municipal solid waste amended soil by acidification in combination with subsequent solubilization of the metallic

Table 4. Means comparison interaction effects of MSW x application years on Ni and Cr (mg/kg) in soil.

Treatment	t-Ni			a-Ni			t- Cr			a- Cr		
	A	B	C	A	B	C	A	B	C	A	B	C
Control	42.35^{de}	41.85^{de}	41.35^{de}	0.97^{g}	0.82^{g}	0.77^{g}	29.30^{e}	28.24^{e}	28.06^{e}	0.02^{b}	0.02^{b}	0.02^{b}
MSW_{20}	43.41^{d}	47.26^{b}	48.49^{b}	1.28^{cf}	1. 53de	2.06^{bc}	34.10^{d}	35.49^{c}	38.96^{b}	0.03^{b}	0.04^{b}	0.07^{ab}
MSW_{40}	45.31^{c}	48.16^{ab}	52.72^{a}	1.81^{cd}	2.31^{b}	3.49^{a}	35.61^{c}	38.67^{b}	43.71^{a}	0.05^{b}	0.06^{b}	0.13^{a}

t, Total; a, available; A, 2006; B, 2006 -2007; C, 2006-2008. Means within the same column and row in each factor followed by the same letter are not significantly different according to DMRT ($p<0.05$).

elements. Courtney and Mullen (2008) stated that the application of two-year industrial municipal solid wastes in loamy sandy soil significantly increased the soil electrical conductivity.

Cr and Ni in soil

Municipal solid waste, years of application and the counter effect of these two had a significant effect on amount of total Ni in soil (Table 2). Three-year application of municipal solid wastes compared with one year application, increased total nickel in soil (Table 4). The highest nickel concentration in soil (52.73 ppm) was observed when MSW_{40} was used for 3 continuous years. It showed 27.52% increase compared with control treatment. The lowest amount of total nickel in soil (41.35 ppm) was seen in control treatment. Absorptivity of heavy metals like nickel depends on various factors, such as pH and type of clay. The higher the pH and more clay the soil becomes, the less the absorptivity of metals. Nickel has the capacity kellate in the presence of organic material. As a result, its absorptivity increases highly making it too toxic (Walker et al., 2004). Qiao et al. (2003), Iwegbue et al. (2007) and Kidd et al. (2007) reported that repeated application of municipal solid waste causes the concentration of heavy metals in soil. Madrid et al. (2007) stated that the application of municipal solid waste during 3 continuous years showed positive increment of Zn, Pb, Cu and Ni in 0–25 cm layer in the amended plot compared with the control.

In relation to the application of municipal solid waste residuals to soil, the main elements generally of concern included Zn, Cu, Ni, Cd, Pb, Cr and Hg (CA, 2001) since they are potentially present in municipal solid waste in the amounts that may be greater than the background values in the receiving soil. Zheljazkov and Warman (2004a) measured similar increases in the total concentrations of Zn, Cu, Ni, Cr and Pb in silty loam soil (pH 6.8) amended with municipal solid waste. Rajaie et al. (2008) found that municipal solid waste increased significantly the Ni concentration in soil. Municipal solid waste, years of application, interaction effect between MSW and application years significantly affect the concentration of available nickel in the soil (Table 2). Also, application of the MSW for 3 continuous years increases available Ni more than one-year application (Table 4). With the increase of municipal solid waste level from 20 to 40 tons per hectare, the available nickel increases in the soil (Table 4). So, the most nickel concentration was observed in a 3-year application of MSW_{40} (3.49 ppm); it showed a significant difference with all MSW levels (Table 4). It has been increased more than 100% compared with control treatment.

The lowest level of available nickel (0.65 ppm) relates to the control treatment. The increase of available nickel is one of the limiting factors for application of MSW as a fertilizer. The significant difference in concentration of available nickel, and one year application of municipal solid waste at both 20 and 40 $ton.ha^{-1}$ treatments, shows the gradual release of this metal. Municipal solid waste contains some nickel, and the acidic pH increases the absorption of nickel in the soil (Malakouti and Homaei, 1994). Smith (2009) reported that long-term application of municipal solid waste increases the absorption of some of heavy metals in soil, in such a way that it damages sensitive plants. Madrid et al. (2007) in their research observed that treating the soil with municipal solid waste increases the extractable forms of heavy metals. Jordão et al. (2006) observed increase in the extractability of heavy metals by DTPA with increasing metal content of municipal solid wastes. There was a significant relationship between municipal solid waste, years of application, interaction between MSW and years of application on total chrome in soil (Table 2). With increase of MSW from 20 to 40 $ton.ha^{-1}$, total chrome increased. This parameter also increased with the increase of application years (Table 4).

The most concentrated Cr was seen in application of MSW_{40} for 3 years. It shows a significant difference with all fertilizer levels. In all levels of treatment, there was a significant difference. In all treatments, total Cr of soil was more than that in control treatment (Table 4). This finding is consistent with Perez et al. (2007) who announced that, after the first year, the addition of municipal solid waste (50, 100, 200 and 400 t/ha) caused an important increase in the total concentration of Cu, Cr and Pb in the soil. The municipal solid waste, years of application and the interaction effect of municipal solid waste and years of application had significant effects on available Cr

Table 5. Analysis of variance of root and shoot of lettuce and radish.

Treatment	Root (Ni)		Shoot (Ni)		Root (Cr)		Shoot (Cr)	
	Lettuce	Radish	Lettuce	Radish	Lettuce	Radish	Lettuce	Radish
MSW	**	**	**	**	**	**	**	**
years application	**	**	**	**	**	**	**	**
MSW years application	**	**	**	**	**	**	**	**

**: significant in 1% levels (based on Duncan test).

Table 6. Means comparison interaction effects of fertilizer * application years on Ni and Cr (mg/kg) in plant organs.

Treatment	Root (Ni)		Shoot (Ni)		Root (Cr)		Shoot (Cr)	
	Lettuce	Radish	Lettuce	Radish	Lettuce	Radish	Lettuce	Radish
2006								
Control	2.82^{d}	2.16^{de}	3.55^{fg}	3.41^{fg}	3.36^{f}	1.67^{fg}	4.16^{c}	3.79^{e}
MSW_{20}	2.71^{d}	2.36^{d}	6.04^{e}	5.16^{de}	4.27^{e}	2.19^{ef}	3.81^{c}	4.76^{d}
MSW_{40}	2.86^{d}	3.38^{c}	8.11^{d}	4.96^{de}	6.49^{c}	3.21^{de}	4.63^{c}	4.93^{d}
2006,2007								
Control	2.41^{d}	2.12^{de}	3.08^{fg}	3.20^{fg}	3.14^{f}	1.52^{fg}	3.66^{c}	3.65^{e}
MSW_{20}	3.38^{c}	3.56^{c}	10.44^{c}	5.85^{cd}	5.79^{d}	3.79^{d}	4.60^{c}	5.70^{c}
MSW_{40}	3.65^{bc}	4.36^{b}	13.51^{a}	6.66^{c}	7.79^{b}	4.98^{c}	6.36^{b}	7.20^{b}
2006-2008								
Control	2.24^{d}	2.08^{de}	3.18^{fg}	3.28^{fg}	3.24^{f}	1.27^{fg}	3.35^{c}	3.33^{e}
MSW_{20}	3.61^{bc}	5.46^{a}	12.06^{b}	9.41^{b}	7.26^{b}	6.27^{b}	5.65^{b}	7.09^{b}
MSW_{40}	5.42^{a}	5.52^{a}	14.23^{a}	11.65^{a}	9.82^{a}	8.47^{a}	9.49^{a}	9.75^{a}

Means within the same column and row in each factor followed by the same letter are not significantly different according to DMRT ($p<0.05$).

(Table 2). Treatments with one-year fertilization at both levels of municipal solid waste contained more available Cr compared with control treatment.

Meanwhile, with the increase of MSW level and years of application, the amount of available Cr increased. In addition, increasing the fertilization from one to three times, the soil Cr increased (Table 4). Therefore, the highest amount of available Cr is seen in 3-years application of MSW_{40} (0.13 ppm). It shows a 100% increase compared with control treatment. According to Pichtel and Anderson (1997), adding the municipal solid waste in proportion with its quantity, increases the absorbable forms of Cr and Ni in the soil. As time passes, the amount of these available materials decreases. Research done by Mohammadinia (1995) in Esfahan University also showed that municipal solid waste leached significantly, increased available Cr of these soils. Weber et al. (2007) reported that the application of municipal solid waste in loamy sand soil during 2 consecutive years caused an increase of Zn, Pb and Cu concentrations already at low application rates and a significant increase of Ni, Cr and Cd at the highest application rates.

Cr and Ni in lettuce and radish organs

MSW level, its application for 3 continuous years and reaction of MSW and years of application, showed significant effects on the amount of Ni in roots and shoots of lettuce and radish (Table 5). With increase in MSW amount, the concentration of Ni in root and radish increased (Table 6). Also, with the increase of fertilization years from one to three years, the amount of Ni in shoots of lettuce and radish increased (Table 6). The highest concentration of Ni in lettuce root was 5.42 ppm and in its shoots was 14.23 ppm. These quantities are seen when applying 40 ton MSW ha^{-1} for 3 continuous years. It showed two and four times increase compared with control treatment (Table 6). The highest concentration of Ni in root of radish (5.52 ppm) was seen after 3 continuous years of applying 40 ton MSW ha^{-1}, which was not different from MSW_{20} treatment.

The highest concentration of Ni in shoots of radish after 3-year application of 40 tons. ha^{-1} was 11.65 ppm. It showed more than 100% increase compared with control treatment (Table 6). The amount of Ni in shoots of lettuce and radish was more than that in the roots. Other studies also showed that the Ni moves in the plant and translocated from roots to the shoot and leaves (Kabata and pendias, 2001). Pichtel and Anderson (1997) detected increased uptake and potentially phytotoxic concentrations of Zn, Cu and Ni in plant tissues of oats grown in a fine-textured soil (pH 6.8) in a pot experiment amended with MSW (manually sorted) and sewage sludge, and this was associated with yield decreases at the highest rates of municipal solid waste application up to 240 ton. ha^{-1} DS. Madhava and Stresty (2000) reported that some heavy metals like Ni and Cd, especially with high concentrations, influence the growth and yield of plants. The toxic effect of heavy metals on plants is the result of production of various kinds of active oxygen (ROS), such as O_2, H_2O_2, and OH.

These types of active oxygen interfere with cells processes. They cause damage in the cellular membrane (Pereira et al., 2002). Zheljazkov and Warman (2004a) observed that with the increase of organic material, the concentration and absorptivity of Ni, Cr and Pb increases too. In other words, we can see the pollution resulting from heavy metals. Based on the above results, Ni is absorbed easily by plants when it is present in the soil. Therefore, a great attention is necessary in its application through using municipal solid waste since Ni is known as a very toxic element which endangers plant's growth. Results of variance analysis (Table 5) showed the significant effect of MSW on the Cr concentration in roots and shoots of lettuce and radish. Also, there was a significant difference between Cr concentration in roots and shoots of these two plants and 3-years application of municipal solid waste. The interaction effect of MSW and years of application on Cr concentration in roots and shoots became significant. Table 6 shows that with the increase of municipal solid waste and years of application, a significant increase of Cr was seen in roots and shoots of lettuce and radish. The concentration of Cr in Lettuce roots was 9.82 ppm and in its shoot was 9.49 ppm.

The amount of Cr increased more than 100% compared with control treatment, after applying 40 tons MSW ha^{-1} for 3 continuous years (Table 7). This amount for radish was 8.47 and 9.75 ppm, respectively. It showed a significant difference with all MSW levels statistically. The lowest Cr concentration in radish relates to the control treatment (Table 7). Comparison of metal concentration in shoots and roots of plants based on the element and plant was different. In all levels of MSW, the amount of Cr in lettuce root was more than that in shoots (Table 2). The accumulation of Cr in root may be regarded as an advantage. It prevents Cr from entering the shoot and food cycle. Kabata-pendias (2001) found that vegetables are more sensitive than grasses against heavy metals which are found more in vegetables, especially lettuce. Some researchers attribute the increase of absorbable heavy metals like Cr and Cd to the application of municipal solid waste to rice and spinach (Razavitusi, 2000).

Conclusion

Application of municipal solid waste increases the amount of organic material and electrical conductivity of soil significantly, in such a way that applying 40 ton MSW ha^{-1} for 3 years has been more in all treatments but it has also decreased pH of soil. Also, concentration of total and available Cr and Ni has increased with the increase of compost level and years of application. On the other hand, the increase of municipal solid waste in soil increased the concentration of Ni and Cr in shoots of lettuce and radish. Ni concentration was less in roots of both plants. Therefore, because of accumulation of heavy metals in soil and their uptake by plants, long-term application of municipal solid waste requires more attention.

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