Heavy Metal Content of Eggplant (*Solanum Melongena*) Grown in The Long-Term MSW Compost Applied Soil and Soil Metal Availability

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Abstract— A greenhouse experiment was carried out to assess heavy metal loading and its availability on the greenhouse soil and uptake of metals by Eggplant (*Solanum melongena*) following MSW (Municipal solid waste) compost application. Municipal solid waste (MSW) compost produced by local municipality facilities for solid wastes recovery was applied to soil for 4 years at 25, 50, 100 and 200 ton ha^{-1} levels.

Heavy metal contents of Eggplant grown in MSW compost applied greenhouse soil were higher than that in untreated soil. Higher levels of MSW compost applications caused higher accumulation of Zn, Cu, Ni, Pb and Cd in the leaves and fruits of Eggplant plant. Concentrations of heavy metals in plants were below the phytotoxic levels. In the MSW compost treated greenhouse soil, according to background and toxicity limits, heavy metal status of Eggplant leaves was ranged from normal to high levels. Heavy metal concentration in Eggplant fruit were below the phytotoxic threshold levels. However, Pb concentration was exceeded safety food metal limit value for edible vegetables at 100 ton ha^{-1} and 200 ton ha^{-1} compost treatments.

The greenhouse soil treated with MSW compost contained higher concentrations of both total and DTPA-extractable metals than that of untreated soil. Results obtained for DTPA extractable metal availability indicated higher relative metal availability in MSW treated soils. Relative metal availability order of metals in MSW treated soils were Pb>Cd>Zn>Cu>Ni. Bioavailable Cd content of control soil was found below the detection limit. The amount of bioavailable metals in the greenhouse soil was significantly high for MSW compost treatments. In MSW compost treatments, total soil metal concentrations were found below the permissible pollutant limits, but the increase in available metal fractions was more marked than those of total concentrations.

Keywords— MSW compost, heavy metal accumulation, metal bioavailability, Eggplant.

I. INTRODUCTION

The high organic matter and nutrient content of MSW composts is seen as an important alternative among organic matter sources, and several studies have shown that use of MSW compost in agriculture has many benefits to soil, crops and environment [1].

Although MSW compost is an important waste management and recovery, the high level of pollutants in its content limits its use and causes concerns in application to agricultural areas. MSW compost often contains potentially toxic elements, that can cause soil contamination, phytotoxicity and undesirable residues in plant and animal products [2]. As a matter of fact, pollution problems may arise if toxic metals are mobilized into the soil solution and are either taken up by plants or transported in drainage waters. Risk for human health may then occur through consumption of such crops and intake of contaminated waters. In the long term, the use of MSW compost can also cause a significant accumulation of Zn, Cu, Pb, Ni and Cd in the soil and plants [3].

The maximum permissible concentrations of heavy metals in surface soils amended with sewage sludge or MSW compost are normally based on total concentration, although it is the bioavailable metal fraction that posses environmental concern [4]. Nevertheless, these criteria are insufficient since mobility, environmental diffusion and bioavailability largely depend on soil physico-chemical characteristics and, likewise, on trace metal chemical forms [5]. From an environmental point of view, the evaluation and forecast of food contamination is related to the bioavailable fraction of heavy metals in soil.

Information on the effects of MSW composts on the heavy metal loading potentials on greenhouse soil and their metal availability are scarce.

The aim of this study was to assess the residual effects of successive MSW compost applications on the total and bioavailable contents of heavy metals in the greenhouse soil, and on the heavy metal accumulation in Eggplant leaves and fruits grown MSW compost treated soil

II. MATERIAL AND METHODS

The experiment was conducted on the greenhouse representative of the major greenhouse vegetable growing area of Turkey Antalya Aksu. The analytical characteristics of the greenhouse soil and MSW compost are shown in Table 1 which also shows the pollutant limits of soil and also organic materials used as soil amendments, permitted by EU legislation [6].

MSW compost was obtained from MSW composting plant. Compost was produced by the composting of the organic fraction of separated municipal solid waste, selected mechanically at the plant. MSW compost was applied to greenhouse selected soil plots for 4 years as an oven-dry basis,

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totaly at 25 ton ha^{-} ($MSWC_{25}$) 50 ton ha^{-1} ($MSWC_{50}$) 100 ton ha^{-} ($MSWC_{100}$) and 200 ton ha^{-1} ($MSWC_{200}$) levels. MSW compost was manually incorporated into the greenhouse soil and mixed throughout the upper 20 cm. An uncontaminated soil for the control treatment was used to compare the effectiveness of MSW compost application in the same greenhouse with all agronomic practices except MSW compost application.

TABLE I. THE ANALYTICAL CHARACTERISTICS OF THE EXPERIMENTAL SOIL AND MSW COMPOST BEFORE TREATMENT, AND THEIR POLLUTANT LIMITS.

Parameters	Soil		Limit values in soil [6]	MSW compost	Limit values in organic materials[6]
Texture	Loam			-	
pH- H_2O (1:5 w/v)	7.37			7.68	
$CaCO_3$, %	7.68			-	
Total N, %	0.17			0.77	
Organic Matter, %	2.33			47	
EC (dS m^{-1})	0.04			8.12	
Zn, mg kg^{-1}	77[1]	14[2]	150-300[1]	988[1]	2500-4000[1]
Cu, mg kg^{-1}	17	5	50-140	105	1000-1750
Ni, mg kg^{-1}	14	0.55	30-75	68	300-400
Pb, mg kg^{-1}	33	8	50-300	313	750-1200
Cd, mg kg^{-1}	*	*	1-3	1,3	20-40

*: Below detection limit (< 0.02 mg kg^{-1}), [1]: Total concentrations (mg kg^{-1} dry wt), [2]: DTPA-extractable concentrations (mg kg^{-1} dry wt)

The experimental plots have been cultivated in four consecutive years with Eggplant at a density of 16666 plants ha^{-1} and each plot (15 m^2) consisted of 20 Eggplant plants in a randomized block design with four replications. The complete greenhouse operations were carried out in the trials. Basic fertilizer was applied with sprinkler irrigation in all plots at the rate of 400, 250 and 350 kg ha^{-1} of N, P and K, respectively.

During the experiment, the plants were irrigated regularly and treated according to common agrotechnical principles. For the determination of heavy metals, both plant and soil samples were taken at the end of experiment. At the beginning of the flowering period leaf samples were collected from each treatment, and fruits were sampled at the full ripening stage. After the harvest of Eggplant, soil samples were taken at the end of harvest, at a depth of 10-20 cm; and these were air-dried and sieved (< 2 mm). Leaves and fruits of Eggplant samples were dried at 65 ºC in a forced-air oven, ground and then digested in aqua regia (1:3 HNO_3/HCl).

For the determination of 'total' heavy metal concentrations, soil and MSW compost samples were digested in aqua regia (1:3 HNO_3/HCl) according to the international standard [7]. DTPA-extractable (rpresents bioavailable fractions) of metals were extracted from soil with diethylenetriaminepentaacetic acid-CaCl2-triethanolamine adjusted to pH 7,3 [8].

Heavy metal (Zn, Cu, Ni, Pb and Cd) concentrations of greenhouse soil and greenhouse plant samples were analysed using ICP-MS under optimised measurement conditions, and all values were adjusted to oven dried (12 h at 105 °C) material.

A statistical variance analysis were performed by using SPSS-16 for Windows program.

III. RESULTS AND DISCUSSION

Total metal contents in the soil

The heavy metal contents of untreated greenhouse soil and organic materials studied (Table 1) are well within the accepted normal range of values. A comparison of metal contents of organic materials with that of untreated soil showed that the metals Zn, Cu, Ni, Pb and Cd were present in MSW compost in greater concentrations than in the soil. The heavy metal concentrations of MSW compost is below the levels indicated by the EU [6] for the agricultural use of waste organic material (sewage sludge).

Successive applications of MSW compost for 4-yr period led to a far greater introduction of the heavy metals examined and brought about a significant increase in their 'total' form in the soil when compared with the control (Table 2). After 4 years of successive MSW compost applications, significant changes in the total contents of Zn, Cu, Ni, Pb and Cd among the treatments were determined. These results agree with the increase of total metal content observed in soils submitted to repeated application of metal-contaminated sewage sludges [12].

The total Zn, Cu, Pb and Ni contents of soil at the beginning of the experiment were 77, 17, 33 and 14 mg kg^{-1}, respectively. Total Cd concentration in the uncontaminated soil was below the detection limit of analytical apparatus (<0.02 mg kg^{-1}). During the trial period, at high application levels of MSW compost, these levels were increased. The Zn, Cu, Pb and Cd variations in treatments were more marked. Variation in Ni concentration was very low. Increasing soil-metal concentrations with increasing MSW compost applications have been reported [13, 14]. In spite of the important increases in Zn, Cu, Pb and Cd contents registered, the total concentrations in the soil remained below the EU legislation [6] for soils.

DTPA extractable metals in the soil

All amounts of MSW compost brought about significant increases in DTPA-extractable metal concentrations in comparison with the control (Table 2). DTPA-extractable Zn, Cu, Pb, Ni and Cd also registered significantly high values in MSW compost treatments. In general, DTPA-extractable metal concentration in the soil increased with increasing MSW compost applications. DTPA extractable Cd concentrations of control treatment were always below the sensitivity of analytical method (0.02 mg kg^{-1}).

TABLE II. TOTAL AND EDTA EXTRACTABLE CONCENTRATIONS OF HEAVY METALS IN THE GREENHOUSE SOIL

	Zn		Cu		Ni		Pb		Cd	
	Total	DTPA Ex.	Total	DTPA Ex.	Total	DTPA Ex.	Total	DTPA Ex.	Total	DTPA Ex.
Control	66	16	22	5	19	0,71	33	8	<0.02	<0.02
MSW^{25}	77	21	24	5	22	0,88	38	12	0,08	0,04
MSW_{50}	88	24	27	8	26	0,90	43	18	0,12	0,04
MSW_{100}	121	25	33	11	28	0,95	52	20	0,18	0.08
MSW_{200}	185	77	41	13	33	1,22	65	27	0,22	0,09
Significance	**	**	*	**	*	*	**	**	*	*

All data are in mg kg^{-1} as dry weight basis. *: Significant with P≤ 0.05; **: Significant with P≤ 0.01; NS: not significant.

To compare the relative availability of different soil metals, DTPA/Total ratio is used to give available metals as a percentage of total soil metal. The relative increases of Zn, Cu, Pb, Ni and Cd for MSW compost in comparison with the control were higher for the DTPA-extractable than for the 'total' form. Relative metal availability, was greater for Zn, Cu, Pb and Cd than Ni in the greenhouse soil. Relative metal availability order of metals in MSW treated soils were Pb>Cd>Zn>Cu>Ni. Relative availability of metals was the least for control treatment, and was generally the highest for MSW_{200} treatment (Figure 1).

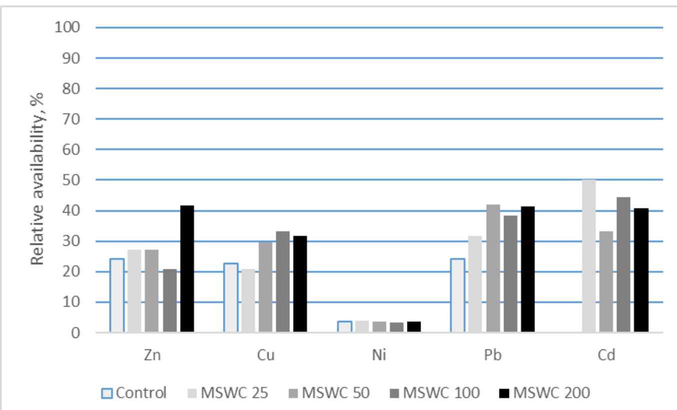

Fig. 1. Relative availability of heavy metals in MSWC treatments

Although total concentrations of all metals were found below the pollutant limits, it can be seen that the increase in DTPA-extractable fractions was more marked than those of total concentrations. These results support the hypothesis [15] that metals added with sewage sludge or other organic wastes may be more mobile in soil than native metals.

Plant Heavy Metal Contents

Metal concentrations of plant leaves in the control treatment were small and representative of background levels [9] (Table 3). The concentration of Cd in the fruits of Eggplant plant grown in control medium was small and below the detection limit of analytical apparatus. As would be expected, heavy metal concentrations of Eggplant leaves in MSW compost treatments were higher than that of control treatment. Higher levels of MSW compost applications caused higher accumulation of Zn, Cu, Ni, Pb and Cd in the leaves and fruits of Eggplant plant.

Limit values of Pb and Cd in edible vegetables were suggested as 0.25 and 0.1 mg kg^{-1} in fresh material [10] (corresponding about 2.5 and 1.0 mg kg^{-1} dry weight basis, respectively). Although Zn, Ni, Pb and Cd contents of Eggplant leaves in MSW compost treatments showed that the amounts were significantly below the phytotoxic threshold levels [11], foodstuff index and limit values of Pb in Eggplant fruit were exceeded by all MSW compost treatments (Table 3).

TABLE III. HEAVY METAL CONTENT IN THE LEAVES AND FRUITS OF EGGPLANT GROWN IN MSW COMPOST APPLIED SOIL.

Treatments	Zn		Cu		Ni		Pb		Cd	
	Leaves	Fruit	Leaves	Fruit	Leaves	Fruit	Leaves	Fruit	Leaves	Fruit
Control	28	4,1	8	3,2	0,8	0,8	1,3	0,09	<0.02	<0.02
MSW^{25}	28	4,0	9,1	5,2	1,5	0,9	2,5	0,12	0,2	0,03
MSW_{50}	35	5,2	10,2	7,7	2,6	1,1	3,6	0,22	0,4	0,03
MSW_{100}	58	6,2	14	8 b	4.1	1.9	6,8	0,45	0.7	0.04
MSW_{200}	77	7,2	16	12	7.3	5,2	10,5	1,25	0,9	0.06
Significance	**	**	**	**	*	*	**	**	*	*
Background levels [8]	40		8		2		3		<0,5	
Phytotoxic level [10]	100-400		20-100		10-100		30-300		5-30	

All data are in mg kg^{-1} dry matter weight. *: Significant with P≤ 0.05; **: Significant with P≤ 0.01

IV. Conclusion

MSW compost applied to the soil for 4 years provided a significant increase in soil total and available metals. Although there was no phytotoxicity on the plant growth by MSW compost treatments, due to cumulative accumulation and also high bioavailability of metals, plant Pb metal content exceeded safety food metal limits. The findings on the effects of heavy metal accumulation in the soil as a result of successive applications of MSW compost to greenhouse soil could be thought a noticeable evidence for the safety reuse concerns of MSW compost. Although MSW composts are an important alternative in waste management and recycling, special legal regulations are required for their application to soils, as is the case with treatment sludge.

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