Metal bioavailability and uptake by Potato plants (Solanum Tuberosum L.) grown in soils amended with MSW Compost

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***Abstract*---A field experiment was conducted to determine the effects of MSWC (municipal solid waste compost) as an organic material source on the growth and the accumulation of heavy metals in potato plant (*Solanum tuberosum* L.) and to assess heavy metal loading and its bioavailability and trace metal speciation on the greenhouse soil. MSWC was applied to plots at 0, 80 and 160 T/ha rates as an oven-dry basis, and potato plants were cultivated under field conditions. Plant vegetative dry weight, potato yield and Zn, Cu, Ni, Pb and Cd contents in the leaves and tubers of potato and soil metal speciation and total and bioavailable metals of experimental soil were determined.**

MSWC amendments increased total and DTPA extractable metals in the soil compared with the control. Increase in bioavailable metal concentrations by the treatments were more marked than those of total concentration of metals. Metals entered soil by MSWC were mostly in mobile fractions. The mobility factor of metals was increased by MSWC treatments, and mobility factor of Cd was the highest among the metals.

The effects of MSWC amendments on the vegetative dry weight and tuber yield of potato were found statistically important. MSWC application at 80 T/ha rate were supplied better yield results than that of control. Although MSWC led to greater dry matter at low application rates, 160 T/ha application rate of MSWC depressed plant growth, leaf dry matter and potato yield. However, MSWC applications brought about a sharp increase for heavy metals in the plant material. In the MSWC treatments, at 160 T/ha treatment, concentrations of Zn, Pb and Cd in potato tubers were exceeded limit values for edible vegetables. The resulting data demonstrate that metals were accumulated in potato tubers and safety food metal limit values for edible vegetables were exceeded by MSWC applications.

Key words: **Bioavailability, Metals, MSW compost, Potato**

I. Introduction

Composting of municipal solid waste and its subsequent application to agricultural land is gaining popularity because of environmental concerns associated with the disposal of this material in landfills. Several studies have shown that use of MSWC in agriculture has many benefits to soil, crops and environment [1]. However, heavy metal pollution of agricultural soils and crops through the applications of MSWC are of great concern. Although MSWC provides nutrients for plant growth, its continual use over extended periods can result in the accumulation of heavy metals in soils and in the crops to levels that are detrimental to the food chain [2].

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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 MSWC can also cause a significant accumulation of Zn, Cu, Pb, Ni and Cd in the soil and plants [3]. Contamination of soils by potentially toxic elements is subject to strict controls within the European Community in relation to total permissible metal concentrations, soil properties and intended use.

The maximum permissible concentrations of heavy metals in surface soils 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. Therefore, the chemical form is of great significance in determining the potential bioavailability and remobilization of the soil metals [6].

The aim of this study was to assess the effects of MSWC applications on the heavy metal accumulation in potato plant and to provide information on the metal fractionation, and to evaluate the total and bioavailable (DTPA-extractable) contents of Zn, Cu, Ni, Pb and Cd in the greenhouse soil.

II. Material And Methods

A field experiment was carried out in an experimental soil (Red Mediterranean Soil [7]) from fields cropped in a wheat-corn rotation in Antalya, and potato plant was grown in soil treated with MSWC. The analytical characteristics of the greenhouse soil and MSWC 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 [8].

The MSWC was obtained from the solid waste composting plant, Kemer, Antalya. Compost was produced by the composting of the organic fraction of unseparated municipal solid waste, selected mechanically at the plant. The MSWC were air-dried, mixed and sieved through a 2- mm-mesh sieve before application to plots.

The experimental plots have been arranged as 5.6 m^2. MSWC was applied to experimental plots 2 months early before potato cultivation for organic matter incubation. Treatments were consisted of three rates, (0, 80 and 160 T/ha) as dry weight basis of MSWC. 20 healty potato tubers (*Solanum Tuberosum L.*) were embeded per plot using 0.4 m by 0.70 spacing in a randomized block design with three replicates. The complete field operations were carried out in the trials. Before planting, a basic mineral fertilizer was applied to all plots with drip irrigation at the rate of 300, 200 and 300 kg ha^{-1} of N, P and K, respectively. During the experiment, the plants were watered regularly and treated according to common agrotechnical principles.

TABLE 1. THE ANALYTICAL CHARACTERISTICS OF THE EXPERIMENTAL SOIL AND MSWC BEFORE TREATMENT AND THEIR POLLUTANT LIMITS.

Parameters	Soil	Soil Limits [8]	MSWC	Organic M. limits [8]
Texture	Loam		-	
pH- H_2O	7.55		7.77	
$CaCO_3$, %	8.70		-	
Total N, %	0.17		0.72	
Organic M., %	2.35		57	
EC (dS m^{-1})	0.04		6.47	
Zn, mg kg^{-1}	85[1]	150-300 [1]	1220 [1]	2500-4000 [1]
Cu, mg kg^{-1}	17	50-140	105	1000-1750
Ni, mg kg^{-1}	15	30-75	43	300-400
Pb, mg kg^{-1}	33	50-300	196	750-1200
Cd, mg kg^{-1}	0.03	1-3	1.6	20-40

[1]: Total concentrations (mg kg^{-1} dry wt)

Leaf samples were taken at flowering period. Eighty days after sowing, potato plants were reached maturation. Total fresh leaf and potato yields of per plot was recorded at harvest. Leaf and tuber samples of potato plant were dried at 65 ºC for 48 h for determination of plant metal analysis. Plant tissues were ground and then digested in aqua regia (1:3 HNO_3/HCl).

Soil samples were taken at a depth of 10-20 cm and these were air-dried and sieved (< 2 mm). For the determination of 'total' heavy metal concentrations, soil and MSWC samples were digested in aqua regia (1:3 HNO_3/HCl) according to the international standard [9]. Bioavailable fractions of metals were extracted from soil with diethylenetriaminepentaacetic acid-$CaCl_2$-triethanolamine (DTPA) adjusted to pH 7.3 [10] procedure.

The heavy metal sequential extraction procedure [11] had the following steps:

F1. 1 M $MgCl_2$ (1:8 w/v, pH 7) for 1 h at room temperature; metals in soil solution and in exchangeable forms.

F2. 1 M NaOAc (1:8 w/v, pH 5) for 5 h at room temperature; metals mainly in the carbonate fraction.

F3. 0,04 M NH_2OH/HCl in 25 % (v/v)HOAc (1: 20 w/v) for 6 h at 96 °C ; metals associated with Fe and Mn oxides.

F4. 3 ml 0,02 M HNO_3+5 ml 30 % H_2O_2 (pH 2) for 3 h at 85 °C; metals associated with organic matter.

F5. HNO_3-HCl digestion; residual fraction.

Total, bioavailable and sequentially extracted concentrations of Zn, Cu, Ni, Pb and Cd greenhouse soil and same metals in digested plant samples were determined by ICP-MS under optimised measurement conditions, and values were adjusted for oven dried (12 h at 105 °C) material.

Statistical analyses were performed by using SPSS-16 for Windows program.

III. RESULT AND DISCUSSION

1. Soil Metal Characteristics

The heavy metal contents of untreated greenhouse soil and MSWC (Table 1) are well within the accepted normal range of values. A comparison of metal contents of MSWC with that of untreated soil showed that the metals Zn, Cu, Ni, Pb and Cd were present in MSWC in greater concentrations than in the soil. The heavy metal concentration of MSWC is below the levels indicated by the EU [8] for the agricultural use of waste organic material (sewage sludge).

Applications of MSWC led to a far greater introduction of the heavy metals examined and brought about a significant increase in their total and 'DTPA extractable' form in the soil when compared with the control (Figure 1 and Figure 2). The total Zn, Cu, Pb, Ni and Cd contents of soil at the beginning of the experiment were 85, 17, 15, 33 and 0,03 mg kg^{-1}, respectively. After the end of experiment, total and 'DTPA extractable' contents of Zn, Cu, Ni, Pb and Cd in experimental soil were increased.

Increasing soil-metal concentrations with increasing MSWC applications have been reported [12]. In spite of the important increases in Zn, Cu and Pb contents registered, the concentrations in the soil remained below the EU legislation [8] for soils. All amounts of MSWC brought about significant increases in total and DTPA-extractable metal concentrations in comparison with the control (Figure 1 and, Figure 2). Total and DTPA-extractable Zn, Cu, Pb, Ni and Cd concentrations in experimental soil also registered significantly higher values in 160 ton ha^{-1} ($MSWC_{160}$) than in 80 ton ha^{-1} ($MSWC_{80}$) application level of MSWC.

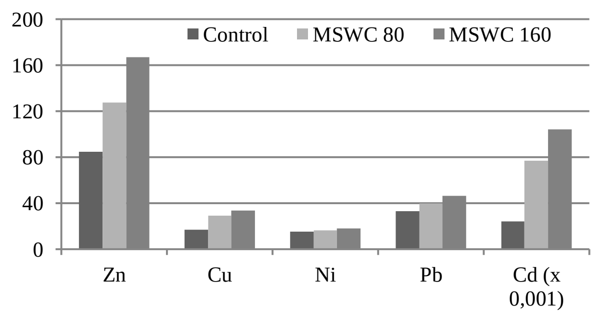

Fig. 1: Total metal concentrations in MSWC applications

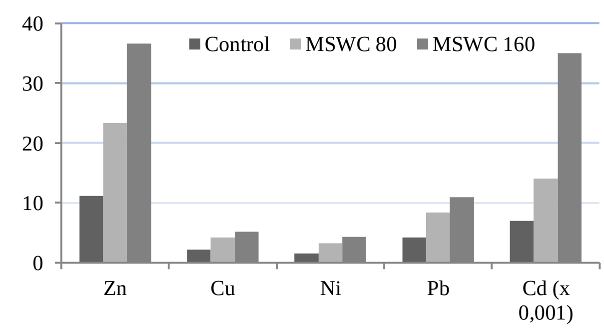

Fig. 2: DTPA-extractable metal concentrations in MSWC applications

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 [13] that metals added with MSWC or other organic wastes may be more mobile in soil than native metals.

Concentrations of Zn, Cu, Ni, Pb and Cd in control soil fractions were given in Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7, respectively

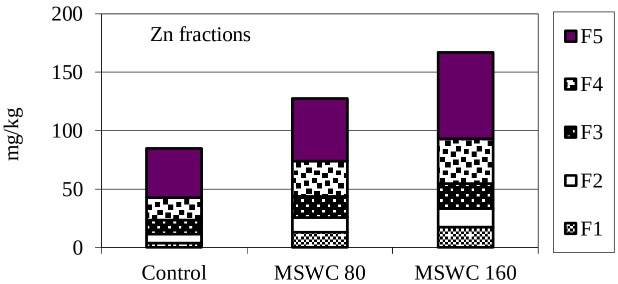

Fig. 3: Distrubution of Zn in the different fractions of MSWC applied soil

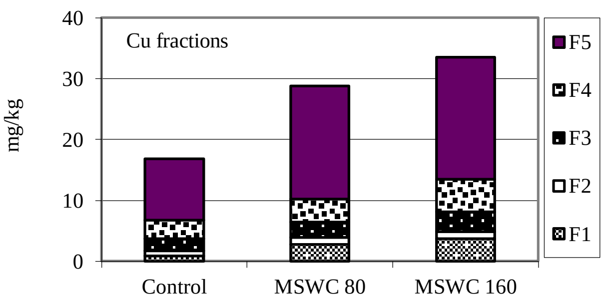

Fig. 4: Distrubution of Cu in the different fractions of MSWC applied soil

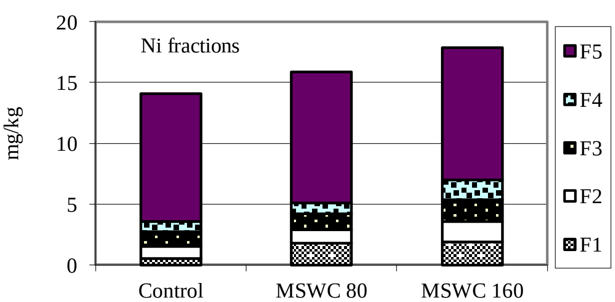

Fig. 5: Distrubution of Ni in the different fractions of MSWC applied soil.

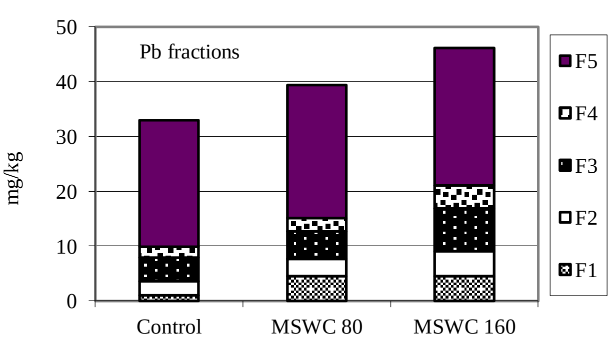

Fig. 6: Distrubution of Pb in the different fractions of MSWC applied soil

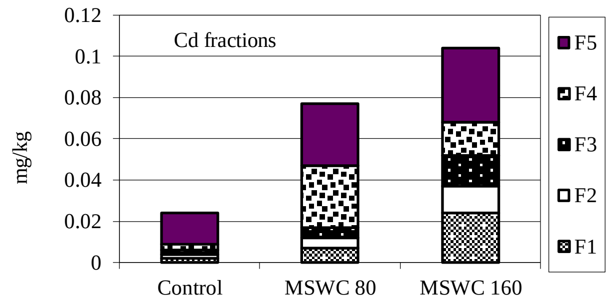

Fig. 7: Distrubution of Cd in the different fractions of MSWC applied soil

In sequential extraction procedure, for all metals, agreement between fractional total metal values and aqua regia extractable metal values are generally acceptable (100±5 %) rate. The study of the distribution of metals in control soil showed that the greatest percentage of all metals was present in the residual fraction (F5). The residual phase represents metals largely embedded in the crystal lattice of the soil fraction and should not be available for remobilization except under very harsh conditions [6]. Although F1, F2 and F3 fractions of control soil were low levels, these fractions of metals were considerably increased by the MSWC applications. The exchangeable (F1) and acid-extractable fractions (F2) are considered to be easily soluble and available. Soil pH has a direct impact on the mobility of metals as it affects their solubility and their capacity to form chelates in soil [14]. It has been reported that more than 50 % of the Pb fraction was residual fraction by the MSWC amendments, but the amount of exchangeable Pb increased over the course of the experiment [15]. Present study showed that the bioavailability of metals in MSWC treatments increased over the incubation.

MSWC applications increased higher percentages of metals in soluble, exchangeable and bound to Fe-Mn oxide fractions both in $MSWC_{80}$ and $MSWC_{160}$ treatment levels. This property naturally gives these metals a high mobility. Despite the low total Pb and Cd concentrations in MSWC studied, the high solubilities of Pb and Cd in the exchangeable phase indicates that these elements could cause environmental damage and thus, the rate of MSWC application should be taken into account [16].

The mobility of metals in control and MSWC treated soils may be assessed on the basis of absolute and relative content of fractions weakly bound to soil components. The relative index of metal mobility was calculated as a ratio of sum of water soluble, exchangeable and carbonate fractions to sum of all fractions, and this described as a mobility factor [17]. MSWC amendments led to mobility factor of metals increase significantly (Figure 8).

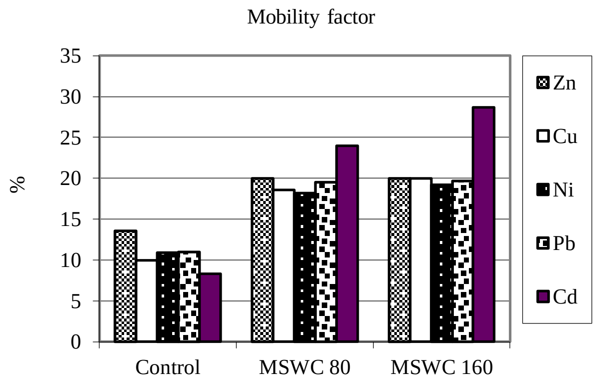

Fig. 8. Mobility factors of Zn, Cu, Ni, Pb and Cd in soils amended with MSWC

The results of the present study suggest that the mobility of metals declines in the following order:

Control soil: Zn>Pb>Cu>Ni>Cd

$MSWC_{80}$ applied soil: Cd>Zn≥Pb>Cu>Ni

$MSWC_{160}$ applied soil: Cd>Pb>Cu>Zn>Ni

As can be seen, MSWC amendments cause a dramatically metal accumulation in soil. More than that metals sourced by MSWC were mostly in the mobile forms. The highest mobility factor was obtained in MSWC160 amendments and Cd was the most mobile element.

2. *Plant Growth and Metal Contents*

Leaf and tuber yields and concentrations of Zn, Cu, Ni, Pb, Cd and Cr in the leaves and tubers of potato plant grown in MSWC treatments, and also background [18] and phytotoxic metal limits [19] are presented in Table 2.

TABLE :. FRESH LEAF AND TUBER YIELDS AND METAL CONCENTRATIONS OF POTATO AMENDED WITH MSWC.

Plant Tissue	Treatments	Yield	Zn	Cu	Ni	Pb	Cd
		g/plot					$mg\ kg^{-1}$
Leaf	Control	25000 b	18 c	5 c	1.3 b	2.0 c	<0.02 b
	$MSWC_{80}$	42800 a	99 b	11 b	10.5 c	26.2b	0.78 a
	$MSWC_{160}$	26600 b	196 a	14 a	12.0 a	39.4 a	0.81 a
Tuber	Control	12640 b	49 c	4 c	1.0 c	2.0 c	<0.02 c
	$MSWC_{80}$	23600 a	108 b	15 b	9.6 b	37.7 b	0.68 b
	$MSWC_{160}$	12740 b	296 a	19 a	14.0 a	44.8 a	0.92 a
Background level [18]			40	8	2	3	<0.50
Phytotoxic level [19]			100-400	20-100	10-100	30-300	5-30

[1] :Means within an amendment followed by the same letter are not significantly different at the <P 0,05 level.

The effects of MSWC amendments on the vegetative dry weight and tuber yield of potato were found statistically important. MSWC treatments increased leaf and tuber yields, and heavy metal concentrations ($P< 0.05$) both in leaf and tuber tissues of potato plant (Table 2). MSWC application at 80 T/ha rate were supplied better yield results than that of control.

Concentrations of Zn, Cu, Ni, Pb and Cd in the control treatment were small and representative of background levels. Heavy metal concentrations in the leaf and tuber tissues of potato in MSWC treatments were higher than that of control. Although MSWC led to greater dry matter at low application rates, 160 T/ha application rate of MSWC depressed plant growth, leaf dry matter and potato yield. This was possibly may be caused higher salt content of MSWC (Table 1).

The concentration of Cd in the leaf and tuber tissues of potato grown in control treatment was small and below the detection limit of analytical apparatus. Vegetable and tuber yields and Zn, Cu, Ni, Pb and Cd concentrations in potato were increased by increasing applications of MSWC. According to background and toxicity limits, metal status of leaves was generally ranged in normal levels and metal concentrations were not reached phytotoxic levels . However, concentrations of total Zn, Cu, Ni and Pb in the $MSWC_{160}$ treatments were particularly large and near to toxic level.

Tuber tissue of potato contained higher metal concentrations than that of leaf tissue. This is important because of edible fraction of plant. Limit values of Pb in edible vegetables were suggested as 0.25 mg kg^{-1} in fresh material [20] (corresponding about 2.5 mg kg^{-1} dry weight basis). Therefore based on the results of current experiment, Pb concentrations of potato in MSWC treatments were exceeded limit values for edible vegetables.

III. CONCLUSIONS

The results of the present study indicated that soil application of MSWC increased total and DTPA extractable metals in the soil compared with the control. MSWC amendments also increased exchangeable, carbonate bound and Fe-Mn oxide bound metals in the soil. Increase in bioavailable metal concentrations by the treatments were more marked than those of total concentration of metals. Specially, these metals entered soil by MSWC were mostly in mobile fractions.

MSWC applications to soil lead to harmful accumulation of heavy metals in the plant. In this short-term study no phytotoxic effects of MSWC on potato plant were detected. However, metals were accumulated in potato tubers and safety food metal limit values for edible vegetables were exceeded by MSWC applications. Taking into consideration the long-term applications of MSWC would carry a risk of progressive of heavy metals to toxic levels. Thus, regular MSWC, soil and plant analysis are needed to check for low levels of MSWC-borne metals used as soil amendments. In the future studies biosolid cleaning technologies involving phytoremediation technics should be taken into consideration for the composting and safety usage of MSWC.

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