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Effects of Adding MSW Compost, Lime and Commercial Soil Improvers on Soil Heavy Metal Concentrations

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In this study, it was aimed to improve the soil with low pH and high amount of heavy metals by using municipal solid waste compost, lime and commercial soil improvers (Terra B and Viro Bind). In this study, the forms of the metals in the soil were determined by using sequential extraction method. It was investigated how soil improvers added to soil change the forms of metals. It was also investigated how the addition of soil improvers (compost, lime and commercial soil improvers) to the soil affects the amount of metal deposited on the roots and stems of the plants (Zea mays). It has been observed that the improvers added to the soil increase the pH value of the soil as T50 > Compost > Lime > A2. The sequential extraction results revealed that exchangeable forms of the studied heavy metals were transformed into the organically bound form. When compared with the control, high concentrations of the metals (except Ni) were found in the Organic Matter (OM) bound and residual forms following the addition of commercial soil conditioners such as A2 and T50, respectively. For the metals measured in the study, with the addition of A2, 96% of Pb, 99% of Cu and Cd, 86% of Ni and 97% of Zn are transformed into OM bound and residual forms, and with the addition of T50, 80% of Pb, 99% of Cu, Cd and ZN, and 78% of Ni were converted to OM bound and residual forms. These results indicated that the application of 1.5% lime combined with 10% compost substantially enhanced plant growth in the contaminated soils.

Keywords: Extraction, Soil contamination, Soil remediation, Waste, *Zea mays*

Introduction

Some heavy metals in high concentrations can adversely affect plants and humans and animals that feed on plants. If Chromium, Nickel and Lead are found in soils between 10–100 mg/kg and cadmium below 1 mg/kg, these amounts are considered normal levels. Extractable heavy metal concentrations in soils: in cases where it is over 1 mg/kg for Cd, over 0.1 mg/kg for Cu and over 100 mg/kg for Ni, toxic effects may occur.[1]

Metal concentrations in soil range from 1 mg/kg (ppm) to 100,000 mg/kg, either as a result of human activities or depending on the geological origin of the soil. Excessive concentrations of some heavy metals in soils such as Cd, Cr, Cu, Ni and Zn cause the deterioration of natural aquatic and terrestrial ecosystems. Some heavy metals are important micro-elements for plants at low doses; however, high doses inhibit the growth of most plant species and may cause metabolic dysregulation.[2]

The dosages and concentrations of the heavy metals and their physical and chemical forms make them mobile or biologically available. The diffusion of the heavy metals into the environment may occur through a wide range of processes and paths, including air, surface waters, and soil.[3]

The bioaccumulation of heavy metals in plants and animals has proven to have toxic effects. Because of this, applying remediation techniques to areas contaminated with heavy metals is very important.[4,5]

Arable land is degraded into desert partly due to the increasing rates of global warming, agricultural fertilizers and pesticides, and thus, becomes unfit for agriculture. Thus, the possibilities to feed an increasing population are decreasing. Moreover, there are no new lands for production and the existing lands are being lost and destroyed.[6,7]

It is possible to improve the soils contaminated with metals with phytoremediation, soil washing, stabilization, solidification, electroremediation, and excavation.[8,9]

Among these methods, improvement strategies that enable in situ immobilization of pollutants by adding various substances to contaminated soils are highly effective and can be applied to large areas. In addition to the positive effects on soil improvement, the use of

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these substances is also considered as an alternative to the beneficial reuse of wastes.[10]

The addition of organic substances to contaminated soils (e.g. compost) results in positive or negative effects on the mobility of the metals depending on the properties of the material and the receiving soil.[11,12]

Agricultural lime is a natural soil conditioner that increases the pH of acidic soil and improves soil fertility and quality. Adding lime to the soil is one of the most common remediation methods and can lead to the precipitation of heavy metals as metal-carbonates and significantly reduce the exchangeable parts of the heavy metals in soils.[13–18]

In this study, soil with an acidic character and containing high concentrations of heavy metals was used. This soil is one with no plant growth on it. The main purpose of the study is to investigate whether and how the use of soil improvers (MSW compost, lime and commercial improvers) to improve the acidic soil affects the transmission of heavy metals from soil to plant. The novelty of this study is that this study evaluates the performance of MSW compost, lime, and commercial soil conditioners together.

Materials and Methods

Soil Sampling Area

The soil sample used in the study was taken from a field (40°54'35.0"N 40°10'14.3"E) in the Trabzon province in Turkey. There is no industrial facility, traffic area, or developed settlement area around the site. There are hazelnut fields around the working site. It is not located in a location that can be contaminated by any wastewater discharge. Soil naturally contains such high concentrations of heavy metals, there is no discharge.

Preparation of Experiment Sets

The Municipal solid waste (MSW) compost used in this study was obtained from İSTAÇ Kemerburgaz Recovery and Compost Facility. The commercial soil conditioners called Terra B (A2) and ViroBind (T50) were obtained from the Virotec Company. $CaCO_3$ (agricultural lime) was used as lime.

In order to prepare the experimental sets, the soil sample used in this study was ground, after being air dried, and homogenized by sieving (30 mesh) and the mixtures in pots were prepared using this homogeneous soil. Then, the mixtures (mixtures prepared on the basis of volume / volume (v / v)) were placed in pots (150 mL volume) in duplicate. In order to allow for the substances added to the soil to react, only watering was applied to the pots for one week. At the end of one week, the seed of the corn (Zea mays) was planted one per pot. Before planting the corn seeds in pots, they were washed with distilled water to remove any contaminants. The pots were then placed under automatic timer-controlled lighting, which was set to be exposed to daylight for 16 hours day and 8 hours at night. The growth of the corn plants was observed during 40 days.

Analysis

For the measurement of the pH values of the soil sample and of the mixtures placed in pots, 1: 2.5 (w/v) ratio (soil: solution) was added to 0.1 N KCl and mixed, and the pH was measured after 10 minutes (with a Jenway 3040 Ion Analyzer).[19]

For the determination of the pH of the compost, the compost sample was mixed with water at a ratio of 5: 2 (2 g compost, 5 mL distilled water) and then measured with a pH meter (Jenway 3040 Ion Analyzer).[20]

The elemental analysis of the compost and soil samples was carried out with an elemental analyzer (Thermo-Flash 2000) at Istanbul University-Cerrahpaşa Environmental Engineering Department. The ASTM-D5373 (21) method was used for analysis.

The soil and compost samples' organic matter (%) determination was carried out in the Haliç Environmental Laboratory.

For the determination of the total metal concentrations and some elements (Mg, Ca, Na, and K), the samples from the soil, the pots, and the compost were thoroughly grounded with porcelain mortar. Then, microwave digestion was done with the EPA Method 3051A.[22] After the digestion, the samples in Teflon containers were filtered (MN 640 de, 125 mm Macherey-Nagel filter paper) and the filtrate was taken to the HDPE containers and their volumes were completed to 50 mL. The concentrations of metals and some elements were measured using the ICP optical emission spectrometer (Perkin Elmer Optima 7000 DV) in combination with an autosampler (Perkin Elmer S10 Autosampler) at the Bahçeşehir University Environmental Engineering laboratory.

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For the sequential extraction, 3 grams of the sample were placed in 50 cm^3 polypropylene centrifuge tubes. For the determination of the concentrations of the heavy metals in which forms, the extraction steps were applied.[23]

The amounts of the metals (Cu, Ni, Zn, Pb, Cd, Fe, Mn) were determined by using ICP-OES (Perkin Elmer Optima 7000 DV) in the prepared samples.

By using the reference soil, the accuracy of the measurement results was checked. As a reference soil, the NCS Certified Reference Material NCS ZC73002 was used. The analytical precision measured as relative standard deviation is generally determined to be between 5% and 6%.

Results are shown with mean values along with standard deviations.

Results and Discussion

Soil Characterization

The soil and compost characterization is shown in Table 1. When the characterization of the soil is considered, it is seen that it has an acidic character (pH 3). It was seen that the C and N content of the soil was very low while the metals (Fe, Mn), heavy metals (Pb, Cd, Ni, Cu, Zn), and other elements' values (Ca, Na, Mg, K) were high (Table 1).

The change in the pH values of the mixtures in the pots during the study are shown in Table 2. In the literature, it is stated that the corn plant is a plant that grows in soils with a pH value between 5.5–8.(24) When the pH values of the soil mixtures in the pots were examined, it was seen that the pH values of the mixtures 4, 5, 6 and 7 were at the neutral pH level. It is stated in the literature that the addition of organic improvers such as compost to the soil increases the pH value of the soil.[10,14,25] On the other hand, it is stated in the literature that lime addition to soil also increases the soil pH.[12–18, 26] The same tendency was observed when we looked at the pH values measured in this study (Table 2).

Table 1 — Characterization (mean ± Standard deviation) of soil and compost used in the study

Parameters	Compost	Soil
pH	7.9 ± 0.01	3 ± 0.01
Organic Matter (OM) (%)	1.36 ± 0.001	28.4 ± 0.02
C (%)	11.07 ± 0.001	0.1 ± 0.0002
H (%)	ND	0.76
N (%)	0.28 ± 0.001	ND
S (%)	0.17 ± 0.0015	0.09 ± 0.001
Ca, mg/kg (d.w.)	22727 ± 22.22	4045 ± 4.016
Na, mg/kg (d.w.)	17525 ± 10.34	1002 ± 2.03
Mg, mg/kg (d.w.)	5100 ± 3.25	6705 ± 2.023
K, mg/kg (d.w.)	7995 ± 4.17	19022 ± 11.55
Pb, mg/kg (d.w.)	98±0.01	5984 ± 1.52
Cd, mg/kg (d.w.)	0.01±0.0001	367 ± 0.2
Ni, mg/kg (d.w.)	39±0.002	12 ± 0.001
Cu, mg/kg (d.w.)	244±0.3	11206 ± 21.2
Zn, mg/kg (d.w.)	455±0.45	70024 ± 32.55
Fe, mg/kg (d.w.)	16498±25.21	27043 ± 20.56
Mn, mg/kg (d.w.)	356±0.15	389 ± 0.22

ND: Not Detected; d.w: dry weight

Table 2 — Change of pH values (mean ± Standard deviation) of soil and soil mixtures in pots during the study

Volumetric ratios of soil and soil conditioners in pots (v/v)	pH at the beginning	pH at the end of the first week	pH at the end of the study
Soil	3 ± 0.01	3 ± 0.01	3 ± 0.01
Soil + 10% Compost	5 ± 0.015	4 ± 0.02	4 ± 0.01
Soil + 25% Compost	5 ± 0.012	5 ± 0.01	5 ± 0.02
Soil + 50% Compost	6 ± 0.01	6 ± 0.014	6 ± 0.013
Soil + 1.5% Lime	5.5 ± 0.011	6 ± 0.01	6 ± 0.01
Soil + 2.5 %Lime	6.5 ± 0.02	6 ± 0.011	6 ± 0.01
Soil + 1.5% Lime +10% Compost	5 ± 0.01	5 ± 0.022	5 ± 0.015
Soil + 1.5% A2	5 ± 0.012	4 ± 0.011	4 ± 0.014
Soil + 2.5% A2	5 ± 0.01	4.5 ± 0.01	4 ± 0.012
Soil + 5% A2	4 ± 0.013	4 ± 0.011	4 ± 0.01
Soil + 2.5% A2 + 10% Compost	4 ± 0.01	4 ± 0.012	4 ± 0.01
Soil + 0.5% T50	4 ± 0.012	4 ± 0.011	4 ± 0.01
Soil + 1.5% T50	5.5 ± 0.01	5.5 ± 0.01	5.5 ± 0.015
Soil + 2.5% T50	7 ± 0.016	7 ± 0.015	7 ± 0.01
Soil + 1.5% T50 + 10% Compost	5 ± 0.01	5 ± 0.012	5 ± 0.011

It is thought that the reason why the pH values of the mixtures did not change from the end of the first week of the study to the end of the study was due to the buffering properties of the improvers used in the study.

Sequential Extraction Results

When the results in Table 3 were examined, it was apparent that the Pb in the original soil sample was in the form of residue, in other words mostly in a silicates form, and it can be extracted with NaOH, so it is associated with an organic matter form. By adding compost to the soil, it was found that the amount of Pb, which is in the soil solution and is easily transportable (extractable with $CaCl_2$), decreased significantly with the amount of compost added. Similarly, the amount of Pb, which is in the form that can be extracted with a strong chelator (which can be extracted with EDTA), also decreased with the increase of the amount of compost added (Table 3).

When the lime amount increased with the lime addition, it was seen that the concentration of the Pb in the residual form also increased. In the case of a combination of lime and compost, it was determined that the Pb was easily transported from the exchangeable form to the form associated with the organic matter (Table 3).

As a result of using commercial soil conditioners such as A2 and T50, when the forms in which the Pb exists in the soil were examined, it was observed that the majority of the Pb switched with the 5% (v/v) A2 and 1.5% (v/v) T50 addition to the residual form which is the most inactive form. As a result of using the combination of these substances and compost, it was determined that the amount of mobile forms decreased by approximately 50% by adding A2 to the soil at a rate of 2.5% (v/v) and that when used in combination with 1.5% (v/v) T50 and compost, there was a significant increase in the concentration of the organic bound form of Pb (Table 3).

In the original soil sample, it was found that most of the Cu was in the form of residual, in other words mostly in the form of silicates (Table 3). By adding compost to the soil, it was determined that the amount of Cu in the residual form and the form in the soil solution, which is easily transportable (can be extracted with $CaCl_2$), decreased with the amount of compost added. It was observed that the Cu concentrations in the associated OM form increased significantly with the increase of the amount of compost added (Table 3).

When the lime amount added to the soil increased, the concentration of the Cu in the associated OM form increased and the Cu concentration in the exchangeable form significantly decreased. It was determined that the Cu can easily be transported from the exchangeable form to the associated organic matter form when the lime and compost are used together (Table 3).

Table 3 — Sequential extraction results obtained for Pb and Cu (mg/kg, dry weight)

Sample	Pb				Cu			
	$CaCl_2$ extractable	OM assoc. metals	Strong chelator extracted Metals	Residual metals	$CaCl_2$ extractable	OM assoc. metals	Strong chelator extracted Metals	Residual metals
Soil	558 ± 0.2	2027 ± 1.01	190 ± 0.01	3207 ± 1.21	1099 ± 10.05	1798 ± 10.05	39 ± 0.01	8270 ± 22.11
Soil + 10% Compost	467 ± 0.3	2187 ± 1.0	105 ± 0.02	2206 ± 1.01	534 ± 0.3	2006 ± 20.02	22.6 ± 0.01	8057 ± 20.01
Soil + 25% Compost	64 ± 0.01	2164 ± 1.04	84 ± 0.01	2653 ± 1.4	42 ± 0.02	5381 ± 25.05	8.6 ± 0.002	5733 ± 12.05
Soil + 50% Compost	20 ± 0.01	2499 ± 1.01	49 ± 0.01	2396 ± 1.20	17.7 ± 0.03	5813 ± 20.01	13.6 ± 0.001	5327 ± 14.20
Soil + 1.5% Lime	4 ± 0.002	1411 ± 1.42	123 ± 0.02	3427 ± 1.12	9 ± 0.01	1633 ± 12.20	27.3 ± 0.02	9495 ± 20.50
Soil + 2.5 %Lime	3 ± 0.001	1442 ± 1.01	47 ± 0.001	4186 ± 1.11	5.6 ± 0.01	4126 ± 15.10	11.6 ± 0.01	7021 ± 14.20
Soil + 1.5% Lime +10% Compost	10 ± 0.001	2604 ± 1.31	113 ± 0.01	2238 ± 1.13	2.4 ± 0.001	3019 ± 10.01	47 ± 0.02	8097 ± 13.06
Soil + 1.5% A2	398 ± 0.03	797 ± 0.01	58 ± 0.002	4104 ± 1.41	582 ± 0.2	7094 ± 20.05	16 ± 0.01	3473 ± 10.45
Soil + 2.5% A2	521 ± 1.01	ND	57 ± 0.001	4000 ± 1.40	525 ± 0.1	1356 ± 10.05	18 ± 0.02	9267 ± 18.05
Soil + 5% A2	62 ± 0.002	569 ± 1.21	166 ± 0.01	4168 ± 1.01	39 ± 0.02	4518 ± 17.50	62 ± 0.04	6546 ± 11.35
Soil + 2.5% A2 + 10% Compost	280 ± 0.01	ND	257 ± 0.01	4670 ± 1.11	225 ± 0.1	3913 ± 10.30	76 ± 0.02	6951 ± 12.55
Soil + 0.5% T50	271 ± 0.01	1751 ± 1.11	372 ± 0.02	2571 ± 1.20	678 ± 0.4	3172 ± 10.02	80 ± 0.04	6932 ± 13.05
Soil + 1.5% T50	45 ± 0.002	765 ± 0.01	74 ± 0.001	4080 ± 1.01	5.7 ± 0.02	3624 ± 10.01	17.3 ± 0.01	7519 ± 12.45
Soil + 2.5% T50	13 ± 0.001	1874 ± 0.1	138 ± 0.02	2941 ± 1.13	8.3 ± 0.03	6333 ± 14.05	15.7 ± 0.01	4808 ± 11.43
Soil + 1.5% T50 + 10% Compost	2 ± 0.0001	1617 ± 0.9	279 ± 0.01	3068 ±1.22	3.93 ± 0.01	7435 ± 17.40	77 ± 0.05	4076 ± 10.72

ND: Not Detected; ± Standard deviation

As a result of using commercial soil improvers such as A2 and T50, it was found that the major part of the Cu can turn into the associated OM form and the residual form that is the most inactive form. As a result of using the combination of these substances and compost, it was seen that moving forms, in which 1.5% (v/v) T50 was used without any compost addition, was reduced to almost none, however, there was a significant increase in the concentration of the organic bound form of the Cu with the addition of compost (Table 3).

When the results of the sequential extraction of the soil sample used in the study were examined, it was seen that the Cd in the original soil sample was in a residual form, in other words mostly in the silicates form and in associated organic matter form.

By adding compost to the soil, it was found that the amount of Cd in the soil solution and exchangeable (extractable with $CaCl_2$) form was significantly decreased with the amount of compost added and that the concentration of Cd in the associated OM form increased when the added compost amount was increased (Table 4).

When the lime amount increased with the lime addition, the concentration of the Cd in the form associated with the OM also increased. It was determined that the Cd was easily transported from the exchangeable form to the associated OM form in the case of the combination of the lime and compost (Table 4).

As a result of using commercial soil conditioners such as A2 and T50, when the forms in which the Cd exists in the soil were examined, it was observed that Cd was found to be associated more with the OM and residual forms.

As a result of the combination of these substances and compost, the Cd was found to be associated with the OM and residual forms (Table 4).

When the results in Table 4 are examined, it was seen that the nickel in the original soil sample was in residual form and associated with the organic matter form. With the addition of the compost to the soil, the Ni concentration in the soil OM associated form was significantly reduced by the increasing amount of compost thus, increasing the Ni concentrations in the residual form (Table 4). When the lime amount increased with the lime addition, it was seen that the concentration of Ni in the mobile form also increased. In the case of a combination of lime and compost, it was determined that the Ni could be easily transported from the associated organic matter form to the exchangeable form (Table 4).

When the forms in which the nickel was found were examined, as a result of using commercial soil conditioners such as A2 and T50, it was determined that it could easily change from associated organic matter form and switch to residual forms. It was seen that similar results could be obtained with the combination of these conditioners and compost (Table 4).

Table 4 — Sequential extraction results for Cd and Ni (mg/kg, dry weight)

Sample	Cd				Ni			
	$CaCl_2$ extractable	OM assoc. metals	Strong chelator extracted Metals	Residual metals	$CaCl_2$ extractable	OM assoc. metals	Strong chelator extracted Metals	Residual metals
Soil	14 ± 0.01	148 ± 0.02	0.93 ± 0.001	204 ± 0.01	0.7 ± 0.002	7.2 ± 0.003	0.3 ± 0.001	3.4 ± 0.002
Soil + 10% Compost	8 ± 0.002	106 ± 0.01	0.38 ± 0.001	253 ± 0.02	0.2 ± 0.001	5.3 ± 0.002	0.2 ± 0.001	6 ± 0.003
Soil + 25% Compost	7 ± 0.001	208 ± 0.01	0.75 ± 0.0001	152 ± 0.01	0.3 ± 0.001	1 ± 0.001	0.2 ± 0.001	10 ± 0.005
Soil + 50% Compost	2 ± 0.001	265 ± 0.02	0.85 ± 0.001	230 ± 0.01	1.3 ± 0.001	ND	0.1 ± 0.001	9.4 ± 0.002
Soil + 1.5% Lime	1.6 ± 0.0001	170 ± 0.01	0.7 ± 0.0001	195 ± 0.02	2.2 ± 0.001	7.5 ± 0.004	0.2 ± 0.001	1.7 ± 0.001
Soil + 2.5 %Lime	ND	193 ± 0.01	0.76 ± 0.0001	173 ± 0.01	2.8 ± 0.001	2.6 ± 0.001	0.2 ± 0.001	5.9 ± 0.002
Soil + 1.5% Lime +10% Compost	0.69 ± 0.0001	190 ± 0.02	2.35 ± 0.001	174 ± 0.023	3.3 ± 0.002	2.5 ± 0.001	0.3 ± 0.002	6.5 ± 0.001
Soil + 1.5% A2	7.65 ± 0.001	236 ± 0.01	0.92 ± 0.0001	122 ± 0.01	2.4 ± 0.001	4.3 ± 0.001	0.2 ± 0.001	4.6 ± 0.001
Soil + 2.5% A2	8.85 ± 0.001	147 ± 0.01	0.94 ± 0.0002	210 ± 0.01	3.2 ± 0.002	4.8 ± 0.002	0.2 ± 0.001	5.5 ± 0.002
Soil + 5% A2	5.7 ± 0.001	199 ± 0.02	1.95 ± 0.0001	160 ± 0.011	2.3 ± 0.001	3 ± 0.001	0.2 ± 0.001	7.3 ± 0.003
Soil + 2.5% A2 + 10% Compost	7.41 ± 0.002	187 ± 0.01	3.27 ± 0.0001	169 ± 0.01	2.0 ± 0.001	1.9 ± .001	0.3 ± 0.001	7.3 ± 0.001
Soil + 0.5% T50	8.4 ± 0.001	159 ± 0.01	3.64 ± 0.0002	196 ± 0.02	2.1 ± 0.001	3.4 ± 0.002	0.02 ±0.001	7.3 ± 0.001
Soil + 1.5% T50	1.62 ± 0.0001	168 ± 0.02	0.88 ± 0.0001	196±0.01	3.7 ± 0.002	1.9 ± 0.001	0.11 ± 0.001	6.3 ± 0.001
Soil + 2.5% T50	0.43 ± 0.0001	274 ± 0.021	1.47 ± 0.0001	91 ± 0.001	2 ± 0.001	Not Detected	0.24 ± 0.001	9.3 ± 0.002
Soil + 1.5% T50 + 10% Compost	0.37 ± 0.0001	235 ± 0.01	3.41 ± 0.0001	128 ± 0.002	2.5 ± 0.001	1.5 ± 0.001	ND	7.5 ± 0.001

ND: Not Detected; ±Standard deviation

In the original soil sample, a large part of the Zn was found to be in the form of residual. In addition, the Zn, in the original soil sample, was determined to be in the form associated with organic matter (35%.5) that could be extractable with NaOH (Table 5). By adding compost to the soil, it was determined that the amount of Zn in the exchangeable form (extractable with $CaCl_2$) decreased significantly with the amount of compost added. It was observed that the concentration of the Zn in the form associated with the OM increased when the amount of compost added was increased. When the amount of lime added to the soil was increased, the concentration of Zn in the form associated with the OM increased, while the exchangeable form of the Zn concentration decreases significantly (Table 5). As a result of using commercial soil conditioners such as A2 and T50, it was determined that most of the Zn in the soil is in the OM associated form or in residual form, which is the most immobile form. As a result of using the combination of these substances and compost, it was seen that when used without adding compost, 1.5% (v/v) T50's immobile forms was reduced to almost none, however, with the addition of compost, there was a significant increase in the form of the Zn which can be extracted with a strong extractant such as EDTA (Table 5).

As shown in Table 6, when the results of the sequential extraction for the Fe were examined, it was

Table 5 — Sequential extraction results obtained for Zn (mg/kg, dry weight)

Sample	$CaCl_2$ extractable	OM assoc. metals	Strong chelator extracted Metals	Residual metals
Soil	4174 ±9.05	24858 ± 22.20	49 ± 0.03	40943 ± 31.47
Soil + 10% Compost	2809 ± 5.27	25024 ± 32.55	29 ± 0.02	55207 ± 32.53
Soil + 25% Compost	2358 ± 3.25	38487 ± 35.34	27 ± 0.01	29150 ± 22.54
Soil + 50% Compost	329 ± 0.3	28490 ± 21.55	49 ± 0.04	51716 ± 30.45
Soil + 1.5% Lime	89 ± 0.04	21527 ± 32.40	55 ± 0.05	48353 ± 27.34
Soil + 2.5 %Lime	8 ± 0.002	36892 ± 27.45	36 ± 0.01	33088 ± 22.55
Soil + 1.5% Lime +10% Compost	44 ± 0.02	23488 ± 12.54	109 ± 0.6	46383 ± 28.24
Soil + 1.5% A2	2640 ± 5.22	44693 ± 31.55	43 ± 0.02	22646 ± 32.55
Soil + 2.5% A2	2995 ± 4.28	37065 ± 30.20	53 ± 0.02	29910 ± 22.40
Soil + 5% A2	1974 ± 3.24	24194 ± 22.40	169 ± 0.2	43688 ± 30.26
Soil + 2.5% A2 + 10% Compost	2703 ± 9.27	35288 ± 30.55	170.5 ± 0.5	31862 ± 27.55
Soil + 0.5% T50	2769 ± 9.29	14333 ± 12.30	153 ± 0.4	52767 ± 28.23
Soil + 1.5% T50	34 ± 0.01	30199 ± 25.17	59 ± 0.02	39732 ± 12.45
Soil + 2.5% T50	43 ± 0.02	53504 ± 31.41	52 ± 0.01	16426 ± 17.20
Soil + 1.5% T50 + 10% Compost	3 ± 0.003	18588 ± 12.10	172 ± 1.02	51261 ± 31.46

ND: Not Detected; ± Standard deviation

Table 6 — Sequential extraction results obtained for Fe and Mn (mg/kg, dry weight)

Sample	Fe				Mn			
	$CaCl_2$ extractable	OM assoc. metals	Strong chelator extracted Metals	Residual metals	$CaCl_2$ extractable	OM assoc. metals	Strong chelator extracted Metals	Residual metals
Soil	1456 ± 3.25	112 ± 0.2	0.8 ± 0.001	25475 ± 11.45	17 ± 0.01	152 ± 0.2	0.2 ± 0.001	220 ± 0.3
Soil + 10% Compost	170 ± 0.5	3349 ± 5.45	1.4 ± 0.002	23522 ± 12.43	29 ± 0.03	191 ± 0.3	ND	170 ± 0.1
Soil + 25% Compost	1.2 ± 0.001	ND	1.2 ± 0.001	27040 ± 11.30	46 ± 0.01	110 ± 0.1	0.1 ± 0.001	234 ± 0.3
Soil + 50% Compost	3.6 ± 0.003	5272 ± 4.25	18 ± 0.01	20526 ± 10.65	59 ± 0.04	ND	0.6 ± 0.002	332 ± 0.2
Soil + 1.5% Lime	2.7 ± 0.001	9646 ± 6.27	0.6 ± 0.001	17393 ± 8.45	0.9 ± 0.001	189 ± 0.2	0.1 ± 0.001	199 ± 0.1
Soil + 2.5 %Lime	2.9 ± 0.002	9137 ± 6.25	2.9 ± 0.002	17900 ± 10.21	2 ± 0.002	120 ± 0.1	0.1 ± 0.001	268 ± 0.3
Soil + 1.5% Lime +10% Compost	3.9 ± 0.003	10767 ± 10.48	86 ± 0.3	16186 ± 11.17	0.9 ± 0.001	220 ± 0.4	0.6 ± 0.003	169 ± 0.2
Soil + 1.5% A2	156 ± 0.3	1527 ± 3.29	5.5 ± 0.003	25354 ± 12.43	6.3 ± 0.02	230 ± 0.3	0.1 ± 0.001	223 ± 0.1
Soil + 2.5% A2	133 ± 0.2	7426 ± 5.25	8.7 ± 0.003	19475 ± 10.53	12.7 ± 0.04	150 ± 0.1	0.1 ± 0.001	227 ± 0.3
Soil + 5% A2	2 ± 0.001	15991 ± 11.21	17.4 ± 0.01	11033 ± 10.20	7.8 ± 0.01	233 ± 0.2	0.3 ± 0.002	149 ± 0.2
Soil + 2.5% A2 + 10% Compost	14 ± 0.02	11699 ± 10.17	52 ± 0.1	15278 ± 12.16	23 ± 0.03	231 ± 0.2	0.7 ± 0.004	135 ± 0.1
Soil + 0.5% T50	342 ± 0.7	2178 ± 3.26	26 ± 0.03	24497 ± 15.31	10 ± 0.01	108 ± 0.1	0.7 ± 0.003	271 ± 0.2
Soil + 1.5% T50	1.3 ± 0.001	6262 ± 4.25	3.4 ± 0.002	20766 ± 12.10	1.7 ± 0.001	103 ± 0.3	ND	285 ± 0.2
Soil + 2.5% T50	2.5 ± 0.002	4241 ± 3.22	0.5 ± 0.001	22799 ± 11.70	3.4 ± 0.002	107 ± 0.2	0.2 ± 0.001	279 ± 0.1
Soil + 1.5% T50 + 10% Compost	1.2 ± 0.001	1578 ± 2.26	10 ± 0.005	25453 ± 12.34	1.3 ± 0.001	163 ± 0.4	0.6 ± 0.002	225 ± 0.2

ND: Not Detected; ± Standard deviation

found that the Fe had more residual form (bound with silicates) and that it was in a form that could be extractable with $CaCl_2$ (exchangeable) in the soil where no improvement was made. It was observed that the addition of soil improvers decreased the amount of the Fe extracted with $CaCl_2$ (exchangeable) form and that it switched to be associated with the OM form. It was observed that in the mixtures in which the lime and A2 were added, a large portion of the Fe in the residual form was also transferred to the associated OM form.

When Table 6 was examined, it was seen that Mn in the soil used is in residual and OM associated forms. With the addition of the soil conditioners, it was seen that as the amount of compost increased the Mn associated with the OM decreased and that it passes to residual form and to a form that could be extractable with $CaCl_{2.}$ It was seen that there was not much change in the forms of the Mn in the soil as a result of adding other soil improvers (Table 6).

When the sequential extraction results were evaluated, in general, it could be seen that with the addition of the compost and lime, the metals could easily be transferred from the exchangeable form to the form associated with the OM form. Considering the studies made in the literature, it was stated that the concentrations of metals taken by plants were decreased as a result of adding an organic substance to the soil such as compost. According to those studies, this situation was caused by the increase in pH and by the reactive groups in the organic matter that immobilizes metals by forming complexes with the metals.[10,12,14,23,25,27] Similar to our study, in the literature, it was stated that there was a decrease in the mobile forms of the metals in the soil by adding lime to the soil in the studies with lime.[13–18, 26]

Amounts of Metal and Other Elements in Plant Roots and Stems

In Table 7, the amounts of metal in the plant roots and bodies are presented in mg/kg-dry weight basis.

Table 7 — Amounts of metals and other elements in plant roots and bodies (mg/kg, dry weight)

Sample		Zn	Pb	Cd	Ni	Cu	Fe	Mn	Mg	Ca	Na	K
Soil	Root	833	206	9	ND	1241	17338	12	2903	12900	14538	1738
	Body	ND	ND	ND	ND	ND	9750	79	6992	32806	30361	12625
Soil + 10% Compost	Root	2653	222	13	0.1	2647	2045	20	1559	7230	8263	769
	Body	12000	ND	54	3.9	1533	194	147	3635	10725	9733	16492
Soil + 25% Compost	Root	12852	565	44	3.8	1253	5093	169	2926	10628	10445	2902
	Body	3725	2.4	12	3.2	80	83	141	3285	11080	1435	17634
Soil + 50% Compost	Root	4345	673	25	1.7	837	7406	89	3547	17423	11629	4276
	Body	416	1.5	1.8	1.2	64	84	107	4079	14455	2651	16250
Soil + 1.5% Lime	Root	3972	1472	34	1.6	791	10936	37	2893	9309	2307	5686
	Body	374	1.4	2.3	0.5	54	86	25	3873	5650	3381	7504
Soil + 2.5 % Lime	Root	4573	1308	33	ND	989	9331	39	3242	21977	18648	4711
	Body	244	5.6	0.9	3.4	80	129	26	4002	6888	2923	11568
Soil + 1.5% Lime +10% Compost	Root	4605	1837	37	4.9	1325	11322	77	6714	29847	16950	27004
	Body	1073	30	6.6	1.8	51	326	114	5044	17274	4888	43375
Soil + 1.5% A2	Root	9802	108	39	1.7	3022	934	28	1896	5041	2773	990
	Body	14109	22	52	8	3088	452	72	3674	10805	9606	9972
Soil + 2.5% A2	Root	7903	195	36	1.2	3231	1310	23	2050	7277	5549	1336
	Body	4384	3.8	19	4.4	436	264	51	4853	9753	5721	23263
Soil + 5% A2	Root	34904	1603	111	4.4	3198	18380	131	4087	12018	13102	9916
	Body	7203	54.6	20	2	155	781	81	8541	15261	31205	60129
Soil + 2.5% A2 + 10% Compost	Root	29807	518	105	7.7	3713	3040	202	4933	10088	10538	7368
	Body	7485	5.7	23	3.2	126	222	127	4351	5613	19492	45839
Soil + 0.5% T50	Root	24515	281	2835	4.7	10163	1812	78	15068	5654	12059	3484
	Body	32797	15	129	15	5109	635	221	36088	14285	25669	28543
Soil + 1.5% T50	Root	2339	475	14	4.3	920	4486	38	5092	5533	9662	2692
	Body	964	26	2.6	8	205	566	52	26804	11263	9784	18432
Soil + 2.5% T50	Root	4035	512	23	15	1750	6588	26	8889	6327	805	2493
	Body	304	6.7	0.2	2.4	165	204	23	17613	9548	7804	21069
Soil + 1.5% T50 + 10% Compost	Root	3204	1327	28	3.7	813	8782	60	21623	7038	24363	16014
	Body	617	0.7	3.1	7	409	204	83	32188	4346	5005	33863

ND: Not Detected

Table 8 — Plant heights, weights and root lenghts

Sample	Plant weight (gr)	Body Height (cm)	Root Length (cm)
Soil	0.24	2.5	1.5
Soil + 10% Compost	0.3	6	2.5
Soil + 25% Compost	0.72	31	4.6
Soil + 50% Compost	0.75	45	3.55
Soil + 1.5% Lime	0.71	46.35	9.2
Soil + 2.5 % Lime	0.255	36.35	4.4
Soil + 1.5% Lime +10% Compost	1.25	55.35	11.85
Soil + 1.5% A2	0.22	3.6	1
Soil + 2.5% A2	0.36	8.4	1.4
Soil + 5% A2	0.13	12.7	2.65
Soil + 2.5% A2 + 10% Compost	0.12	16.6	3.4
Soil + 0.5% T50	0.1	5	1.85
Soil + 1.5% T50	0.27	15.25	3.3
Soil + 2.5% T50	0.2	3.85	3.5
Soil + 1.5% T50 + 10% Compost	1.52	47.25	8.85

In Table 8, the number of elements (mg/kg-dry weight) detected in plant roots and bodies except metals are shown.

When the Tables showing the heavy metal amounts in the plant roots and trunks were examined (Table 7), it was seen that the amount of heavy metals detected in plant roots was generally higher than the concentrations determined in the plant bodies.

It was determined that in the roots of the plants growing in the mixtures obtained by 50% (v/v) compost addition to the soil, the heavy metal concentrations were lower for all the heavy metals measured in the study when compared to the other compost mixtures (Table 7). It was also observed that the plant growth was better in this compost-soil mixture than the other compost mixtures (45 cm plant height, 3.55 cm root length and 0.75 gr plant weight) (Table 8). It was determined that the amount of the heavy metals in the bodies of the plants growing in the lime added soil decreased with the amount of lime added (except for Pb and Ni). However, in the roots, Zn and Cu values increases as the lime amount increases while concentrations of the other heavy metals decreased slightly (Table 7).

When the plant height and weight were examined, it was observed that plant growth was better in the soil with 1.5% (v/v) lime added (46.35 cm plant height, 0.705 gr plant weight). At the same time, the plant root growth was determined to be better (9.2 cm) in the soil where 1.5% (v/v) of lime was added. It was observed that the best plant growth with 55.35 cm plant height, 1.245 gr plant weight and with 11.85 cm root length was achieved in the soil where 10% (v/v) of compost and 1.5% (v/v) of lime were added together (Table 8). However, it was seen that in the plants growing in this mixture, the amount of heavy metals accumulated in the plant roots and trunks was higher than when compost (50% v/v) or lime (1.5% v/v) was added to the soil alone (Table 7).

According to the results in Table 7, when the other element concentrations in the plant roots and trunks were examined, it was observed that Ca concentrations of plant roots in the soil mixtures with lime addition were higher than in the other mixtures. However, this increase was not observed in the plant bodies. It was seen that with T50 addition to the soil, the Mg concentrations increase in both the root and stem of the plants. In this study, it was observed that in general, the K concentrations increased in roots and stems with the addition of the soil remedies to the soil. It was observed that the Na concentrations detected in both the roots and stems of the plants decreased with the addition of the conditioners.

It has been observed that concentrations of some heavy metals are high in plant stems but low in roots. In the study conducted by Gheju & Stelescu[28], although it has been stated in the literature that heavy metals can be found in higher concentrations in the roots rather than in the stems, they stated that they detected more Zn in the plant stem in a sample than in the plant roots in their study. It has been stated that this is due to the faster translocation of some heavy metals from the roots to the stem under certain conditions.[28]

When the A2 from the commercial soil conditioners was used, it was seen that as the amount of A2 added to the soil increased, the plant root and body lengths increase. However, the length and weight values of the growing plants were quite low when compared to the plants growing in the compost and / or lime-treated soil (Table 8). In the experiments carried out with A2, it was seen that the best results of plant growth were obtained in the soil where A2 (2.5% v/v) was added together with compost (10% v/v) (16.6 cm plant height, 3.4 cm root length and 0.12 g weight) (Table 8). In this study, when T50 was used, the best result was obtained in the soil mixtures with a combination of 1.5% (v/v) T50 and 10% (v/v) compost (47.25 cm length, 8.85 cm root length, 1.515 g weight) (Table 8). When these results are evaluated, it can be said that the results obtained with the commercial soil conditioner T50 were better than those obtained with A2. However, it is seen that T50 should be used with compost for better results. When the results obtained by using the combination of A2, T50 and lime and compost are examined, it can be said that compared to the A2 and lime, the use of T50 reduces the heavy metal transition from the soil to the plant.

With the addition of lime to the soil, it is thought that there may be three reasons why the metals become immobilized. The first of these reasons: while high H^+ ion concentration (low pH) may reduce the metal adsorption capacity of the soil, it increases the plant's metal uptake by increasing the metal absorption from the soil and the solubility of the metal-associated carbonates[29–31] ; when lime is added, H^+ ions are neutralized and the availability of the metals by the plants is reduced.[32,33] (2) Adding lime may increase the negative surface charge and concentration of Ca^{2+} in the soil. An increased surface negative charge may cause the precipitation of the metals in the soil and Ca^{2+} can compete with metals such as Cd^{2+} on root surface.[13,33,34] (3) It has been reported in many studies that the addition of lime may cause the precipitation of metals in the metal-carbonate form and the formation of hydroxyl species of metals or the reduction of (2+) valence metals to (0) valence, which may cause significant reductions in the exchangeable fraction of the metals in contaminated soil.[31,33,35] These results clearly demonstrate that as a result of liming, higher soil pH plays an important role in reducing the mobility of metals in moderately acidic soils.

Conclusions

When the results were evaluated in general it was seen that the best plant growth was observed in soil with 1.5% (v/v) lime and 10% (v/v) compost added, however, when evaluated together with the amounts of heavy metals detected in the plant roots and trunks, it was thought that it would be more appropriate to use 1.5% (v/v) T50 and 10% (v/v) compost added soil in which the second best plant growth was observed.

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References

1 Okcu M, Tozlu E, Kumlay A M & Pehluvan M, The effects of heavy metals on plants, *Alinteri*, **17(B)** (2009) 14–26.

2 Blaylock M J & Huang J W, *Phytoextraction of Metals*, in Phytoremediation of Toxic Metals: Using Plants to Clean Up The Environment edited by I Raskin and B D Ensley (John Wiley and Sons, Inc,Toronto, Canada) 2000, 303.

3 Khalvati M & Dincer I, *Environmental impact of soil microorganisms on global change, causes, impacts and solutions to global warming*, in I Dıncer, C O Colpan & F Kadiroglu, Chapter 15 (Springer, New York, ISBN 978-1-4614-7587-3) 2013, 233–250.

4 Sezgin N, Nemlioğlu S & Balkaya N, *Ecological risk assessment of heavy metal pollution in urban soils: a case study*, in Recycling and Reuse Approaches for Better Sustainability. Environmental Science and Engineering N Balkaya & S Guneysu (Springer, Cham) 2019, 216.

5 Zhao T, Zhang K, Chen J, Shi X, Li X, Ma Y, Fang G & Xu S, Changes in heavy metal mobility and availability in contaminated wet-land soil remediated using ligninbased poly (acrylic acid), *J Hazard Mater*, **368** (2019) 459–467.

6 Tsiattalos G, *Soil pollution*, 2013, [Avaliable via http://www.everythingconnects.org/soilpollution.html (Accessed 26 October 2021)].

7 Wuana R A & Okieimen F E, Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation, *Inter Scholar Res Network (ISRN) Ecol*, (2011) 1–20.

8 Mulligan C N, Yong R N & Gibbs B F, Remediation technologies for metalcontaminated soils and groundwater: an evaluation, *Eng Geol*, **60(1-4)** (2001) 193–207.

9 Kumpiene J, Lagerkvist A & Maurice C, Stabilization of As, Cr, Cu, Pb and Zn in soil using amendments - a review, *Waste Manage*, **28(1)** (2008) 215-225.

10 Venegas A, Rigol A & Vidal M, Viability of organic wastes and biochars as amendments for the remediation of heavy metal-contaminated soils, *Chemosphere*, **119 (**2015) 190–198.

11 Beiyuan J, Lau A Y T, Tsang D C W, Zhang W, Kao C-M, Baek K, Ok Y S & Li X-D, Chelant-enhanced washing of CCA-contaminated soil: Coupled with selective dissolution or soil stabilization, *Sci Total Environ*, **612** (2018) 1463–1472.

12 Farrell M & Jones D L, Use of composts in the remediation of heavy metal contaminated soil, *J Hazard Mater*, **175(1-3)** (2010) 575–582.

13 Hong C O, Lee D K, Chung D Y & Kim P J, Liming effects on cadmium stabilization in upland soil affected by gold mining activity, *Archiv Environ Contami Toxicol*, **52(4)** (2007) 496–502.

14 Lee T, Lai H & Chen Z, Effect of chemical amendments on the concentration of cadmium and lead in long-term contaminated soils, *Chemosphere*, **57(10)** (2004) 1459–1471.

15 Maier N A, McLaughlin M J, Heap M, Butt M I & Smart M K, Effect of nitrogen source and calcium lime on soil pH and potato yield, leaf chemical composition, and tuber cadmium concentrations, *J Plant Nutri*, **25(3)** (2002) 523–544.

16 Tsadilas C D, Soil pH influence on cadmium uptake by tobacco in high cadmium exposure, *J Plant Nutrit*, **23(8)** (2008) 1167–1178.

17 Tsadilas C D, Karaivazoglou N A, Tsotsolis N C, Stamatiadis S & Samaras V, Cadmium uptake by tobacco as affected by liming, N form, and year of cultivation, *Environ Pollut*, **134(2)** (2005) 239-246.

18 Zhu H, Chen C, Xu C, Zhu Q & Huang D, Effects of soil acidification and liming on the phytoavailability of cadmium in paddy soils of central subtropical China, *Environ Pollut*, **219** (2016) 99–106.

19 Paradelo R, Villada A & Barral M T, Reduction of the short-term availability of copper, lead and zinc in a contaminated soil amended with municipal solid waste compost, *J Hazard Mater*, **188(1-3)** (2011) 98–104.

20 Page A L, Miller R H & Keeney D R, *Chemical and microbiological properties*, in Methods of soil analysis part 2 second edition, Agronomy Series no. 9 (American Society of Agronomy, Madison, Wisconsin USA, ISBN 0-89118-072-9) 1982.

21 American Society for Testing and Materials (ASTM), *Standard test methods for determination of Carbon, Hydrogen and Nitrogen in analysis samples of coal and carbon in analysis samples of coal and coke*, *ASTM-D5373* (ASTM International) 2016, 11.

22 EPA, METHOD 3051A, *Microwave assisted acid digestion of sediments, sludges, soils, and oils*, [http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/3051a.pdf. (2013)].

23 Clemente R & Bernal M P, Fractionation of heavy metals and distribution of organic carbon in two contaminated soils amended with humic acids, *Chemosphere*, **64(8)** (2006) 1264–1273.

24 Babaoğlu M, *Maize Farming*, [https://arastirma.tarim.gov.tr/ttae/Sayfalar/Detay.aspx?SayfaId=89 (2014)].

25 Karlsson T, Elgh-Dalgren K, Björn E & Skyllberg U, Complexation of cadmium to sulfur and oxygen functional groups in an organic soil, *Geochim Cosmochim Acta*, **71(3)** (2007) 604–614.

26 Krebs R, Gupta SK, Furrer G & Schulin R, Solubility and plant uptake of metals with and without liming of sludge-amended soils, *J Environ Quality*, **27(1)** (1998) 18-23.

27 Zeng G, Wu H, Liang J, Guo S, Huang L, Xu P, Liu Y, Yuan Y, He X & He Y, Efficiency of biochar and compost (or composting) combined amendments for reducing Cd, Cu, Zn and Pb bioavailability, mobility and ecological risk in wetland soil, *RSC Advanc*, **5** (2015) 34541–34548.

28 Gheju M & Stelescu I, Chelant-assisted phytoextraction and accumulation of Zn by Zea mays, *J Environ Manage*, **128** (2013) 631–636.

29 Blakel L & Goulding K W T, Effects of atmospheric deposition, soil pH and acidification on heavy metal contents in soils and vegetation of semi-natural ecosystems at Rothamsted Experimental Station, UK, *Plant Soil*, **240(2)** (2002) 235–251.

30 Wang A S, Angle J S, Chaney R L, Delorme T A & Reeves R D, Soil pH effects on uptake of Cd and Zn by Thlaspi caerulescens, *Plant Soil*, **281(1-2)** (2006) 325–337.

31 Yang J E, Kim H J, Ok Y, Lee J & Park J, Treatment of abandoned coal mine discharged waters using lime wastes, *Geosci J*, **11(2)** (2007) 111–114.

32 Ardestani M M & Van G C A, Using a toxicokinetics approach to explain the effect of soil pH on cadmium bioavailability to Folsomia candida, *Environ Pollut*, **180** (2013) 122–130.

33 Yang Y, Chen J, Huang Q, Tang S, Wang J, Hu P & Shao G, Can liming reduce cadmium (Cd) accumulation in rice (Oryza sativa) in slightly acidic soils? A contradictory dynamic equilibrium between Cd uptake capacity of roots and Cd immobilisation in soils, *Chemosphere*, **193** (2018) 547–556.

34 Bolan N S, Adriano D C, Mani PA & Duraisamy A, Immobilization and phytoavailability of cadmium in variable charge soils. II. Effect of lime addition, *Plant Soil*, **251(2)** (2003) 187–198.

35 Khaokaew S, Chaney R L, Landrot G, Ginder-Vogel M & Sparks D L, Speciation and release kinetics of cadmium in an alkaline paddy soil under various flooding periods and draining conditions, *Environ Sci Tech*, **45(10)** (2011) 4249–4255.