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Research Article

Effects of Saharan dust cloud water in the remediation of soil having high heavy metal content

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ABSTRACT

Studies revealed that the precipitation from the Saharan Desert brings on a natural fertilizer effect on the plants, contributing to the growth of plants during daytime. In this study, the effectiveness of the Saharan dust has been investigated in the remediation of soil, which has been a very low pH value and high concentrations of various metals. The effects of using the solution obtained by dilution of Saharan dust (as namely Saharan dust water) and Saharan dust on the development of Phaseolus vulgaris and the amount of metal passing to the plant were investigated. It was observed that no plant growth occurred when no remediation was provided on the soil. When metal amounts penetrating the plant was considered, lower metal concentrations were determined in the plants growing with mixtures in which Saharan dust was added and which were irrigated with Saharan dust water compared to mixtures in which compost was added and which were irrigated with Saharan dust water. It was observed that irrigation with Saharan dust water and/or addition of Saharan dust was making the soil suitable for the growth of the plant by increasing its pH in a similar way as adding compost. It was seen that the compost and Saharan dust, and that the solution obtained by Saharan dust water were enabling remediation in soil containing high amounts of metal and having an acidic character at a level as to enable plant growth, and are causing a decrease in the amounts of heavy metal penetrating the plant.

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INTRODUCTION

Many studies have reported that heavy metal contamination of soil is likely to cause risks and harm to humans and ecosystems (for example, when we are exposed to contaminated soil, food chain or groundwater) [1–6]. Heavy metal concentrations in soil can significantly diverge in uncontaminated soils because of considerable differences in the geochemical compositions of rocks. However,

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contamination that cause from many sources is likely to lead to toxicity as the result of the growth of a high level of heavy metal concentrations in soil organisms and sensitive plants [7]. Mobility and toxicity of heavy metals in soil are determined by their chemical properties, concentrations and availability [8]. Organic substance, clay mineral, pH and oxidation/reduction status are among the features of soil, are parameters which is likely to alter the solubility and mobility of toxic metals [9]. Moreover, the alteration of these parameters is likely to impact the mobility of heavy metals and influce the usage area of soil by transforming the chemical forms of toxic metals, particularly as the change in pH increases in alkaline direction, heavy metals may be immobilized in soil gradually [10]. Several methods in remediating metal-polluted soils occur, such as physical,chemical and biological methods. Most physical and chemical methods (e.g., encapsulation and vitrification) are costly, and they do not prepare the soil proper for plant growth [11]. We should note that the yield strength of soils may be increased using soil remediators in the remediation of contaminated soils. Many materials such as sewage sludge, tree wastes, tea industry wastes, humic acid, straw, farm manure, compost, chicken manure, humus, pumice, hazelnut shell, sawdust are used in the reclamation of contaminated soils [12–14]. Sahara Desert, which is the largest desert of the world with a surface area of 9.149.000 km^2 at the north of Africa Continent, provides a large part of the dust at the northern hemisphere. It is known that dust of annually 80 million tons –arising from the large Sahara Desert at the north of Africa- is being carried to Amazon Region through winds, and contributes to the growth of plants there. Turkey is close to significant deserts of the world as per its location, and each year about 20 million tons of dust transportation is being realized to Turkey from these deserts through the winds as per its latitude values. It has been revealed by the researches made that red sands are being carried to Turkey from the Grand Sahara, Arabia, Iran and Syria deserts [15, 16]. It has been revealed that these precipitations – which were initially considered as contaminating the environment- are causing natural fertilizer effect on the plants, especially in case of their realization during day time, and are contributing to the growth of plants [16]. Dust coming from the Sahara Desert can start many reactions once contact with cloud water, and it results in the formation of decreased iron (Fe^{2+}), oxalate and various basic amino acids. Microorganisms can be propagated using these products [17].

In this study, the effects of irrigation with dust transported from Sahara Desert (is named as Saharan dust) in the remediation of soil contaminated by heavy metals was searched. It was selected green bean (Phaseolus vulgaris) that could be easily adapt to environmental conditions. Moreover, it was tried to determine the soil remediator feature of Saharan dust by the use of Saharan dust instead of compost. Thus, it was tried to determine the role of irrigation with Saharan dust on the growth of plants against the removal of heavy metal toxicity in contaminated soil. This study is the first study in the literature in which Saharan dust was used as a soil remediator in the reclamation of soils contaminated with heavy metals.

MATERIALS AND METHODS

In this study, Municipal Solid Waste (MSW) Compost samples were acquired from Istanbul Solid Waste Recycling and Composting Facility in Turkey. The soil sample (S1) used in the present study was collated from a rural area in Trabzon. The other soil sample (S2) used in this study was a commercial soil (brand of the soil; TROPIKAL). Saharan dust samples that were obtained from southern Tunisia near Tozeur were used.

Characterization of Soil and Compost Samples

Distilled water was added to the samples at a ratio of 5:2 (v/w) to determine the pH values of the compost samples. The measurement of pH values was performed using a pH meter after being mixed by a magnetic mixer for 10 minutes [18]. The pH values of the soil samples were determined in a water suspension 1:2.5 sample: solution ratio and in KCl 0.1 N [19]. A Jenway 3051 pH meter and SIS electrode were used for the determination of the soil's and compost's pH.

The percentages of C, H and N in the compost and soil samples were determined using an elemental analyzer at the Environmental Engineering Department of Istanbul University- Cerrahpasa. Samples were dried at 50°C for 24 hours and ground to a fine powder in a quartz mortar before elemental analysis. The equipment specifications included Thermo Scientific Flash 2000 CHNS Analyzer, temperature: 900 °C; mobile gas He; burning gas O_2.

Soil and compost samples were air-dried and then sieved to pass a 2 mm mesh for determination of total Ni, Fe, Cu, Cd, Zn, Pb and Mn concentrations. The "Microwave Solubilization Method" was used to determine the total metal concentrations of the soil and compost samples [20]. Accuracy was regularly checked by reference digests of standard reference soils (SRM 2711, CMI7004). The analytical precision, which was measured as relative standard deviation, was between three and 5%.

To investigate the immediately available elements, the concentrations for Ni, Fe, Cu, Cd, Zn, Pb and Mn, 2 grams were obtained from each air-dried sample. For the samples, 20 mL was added from 0.01 N $CaCl_2$ solution, and it was then shaken for three hours. Extracts were filtered using a 0.45 μm membrane. Metal concentrations in filtrates were identified [21].

In the identification of potentially available elements, 50 mL of the solution, having a pH value of 4.95 and comprising 0.5M ammonium acetate and 0.02M EDTA, was added to 5-grams air-dried samples. After shaking for one hour, they were centrifuged at 700 rpm for 15 minutes. Extracts were filtered using a 0.45 µm membrane filter. After this, the metal concentrations in filtrates were identified [21].

The EPA Method 1311 was used for the TCLP (toxicity characteristic leaching procedure) leaching test. Soil samples and distilled water (the pH value was adjusted to 4.93 with acetic acid) were mixed at a ratio of 1:10. They were shaken at 250°C for 18 hours at 30 rpm. After the extraction, the mixture was centrifuged at 2000 rpm for 15 minutes. Then, the extracts were filtered using a 0.45 µm membrane filter. Metal concentrations was determined on these filtrates [21].

Metal concentrations of extracts that were obtained at each stage were measured using AAS (Perkin Elmer AAS 400).

Studies with Plant

In this study, compost at ratios of 25% and 50% (v/v) was added to the S1 and S2 soil samples. In the experiments that were performed in parallel, irrigation was made with distilled water and with water obtained by diluting the Saharan dust and by keeping it under day light (this water will be identified with the abbreviation SDSS in this study). In this respect, when the literature is examined, there are studies on the effects of simulated "cloud water" produced by diluting the Saharan dust on plant growth [22]. Moreover, Saharan dust at ratios of 25% and 50% (v/v) was added to the S1 sample, and irrigation was made with the water of Saharan dust. On the other hand, mixtures -obtained by the addition of only compost and only Saharan dust, and by the addition of compost to Saharan dust at ratios of 25% and 50% (v/v)- were prepared, and irrigation was made with distilled water (each pot was watered with 30 ml of distilled water every two days). Seeds of previously germinated green bean *(Phaseolus vulgaris)* plant were added to these mixtures (1 plant was planted in each 300 ml beaker), and the growth of plants was observed. By the end of 30 days' growth period, the plants were harvested, and their heights and weights were measured. After the harvest, the pH values of soil mixtures were measured. Moreover, the samples used and the abbreviations of the samples are given in Table 1. In this study, the aim of adding compost and the Saharan dust to the soil at 25% and 50% rates is to utilize the method which was defined in Kubatoğlu's 1994 study [23], to investigate the effects of soil improvers added to the soil on the development of the plant.

For Saharan dust water (SDSS), 200 g of dried, sieved (30 mesh) and homogenized Saharan dust soil samples were mixed with 2000 ml of deionized water. It was illuminated Saharan with 500-Watt halogen light having a wavelength spectrum of 380–800 nm at a constant temperature (20°C) to simulate the encapsulated dust within a cloud droplet during the day time. Plant samples were first washed with tap water, and then two times with distilled water. The samples were then dried in an incubator at 60°C. AAS (Perkin Elmer AAS 400) device at Yıldız Technical University

Table 1. Samples used and the abbreviations of the samples

Sample	Abbreviation	Sample	Abbreviation
Soil 1 + 0% Compost + irrigated with distilled water	S1-C0-d	Soil 2 + 25% Compost + irrigated with distilled water	S2-C25-d
Soil 1 + 25% Compost + irrigated with distilled water	S1-C25-d	Soil 2 + 50% Compost + irrigated with distilled water	S2-C50-d
Soil 1 + 50% Compost + irrigated with distilled water	S1-C50-d	Soil 2 + 0% Compost + irrigated with Saharan dust water	S2-C0-s
Soil 1 + 0% Compost + irrigated with Saharan dust water	S1-C0-s	Soil 2 + 25% Compost + irrigated with Saharan dust water	S2-C25-s
Soil 1 + 25% Compost + irrigated with Saharan dust water	S1-C25-s	Soil 2 + 50% Compost + irrigated with Saharan dust water	S2-C50-s
Soil 1 + 50% Compost + irrigated with Saharan dust water	S1-C50-s	Compost + 0% Saharan Dust+ irrigated with distilled water	C-s0-d
Soil 1 + 25% Saharan dust dust + irrigated with Saharan dust water	S1-s25-s	Compost + 25% Saharan Dust + irrigated with distilled water	C-s25-d
Soil 1 + 50% Saharan dust dust + irrigated with Saharan dust water	S1-s50-s	Compost + 50% Saharan Dust + irrigated with distilled water	C-s50-d
Soil 2 + 0% Compost + irrigated with distilled water	S2-C0-d	100% Saharan Dust + irrigated with distilled water	s100-d

Environmental Engineering Laboratories was used to determine Ni, Fe, Cu, Cd, Zn, Pb and Mn concentrations in plant samples. Before AAS analysis, plant samples were prepared for analysis by applying a microwave dissolution procedure (by adding 10 mL HNO_3 into 1 gram sample). Using the reference soil, the accuracy of the measurement results was checked. Reference soil NCS Certified Reference Material NCS ZC73002 was used. Analytical precision measured as relative standard deviation is between 5% and 6%. In this study, all experiments and analyzes were repeated three times. The results were presented as mean values and standard deviations.

Statistical Analysis

A Mann-Whitney U Test was used to find out whether there was a difference in irrigation types and soil types. All analyses were conducted using the significance level 0.05 using the SPSS v20 software (IBM, USA).

RESULTS AND DISCUSSION

In Table 2, the characteristics of compost, Soil 1 and 2 and Saharan dust, which were used in the study, were presented. When pH values in Table 2 were compared with the values in Table 3, it was observed that Soil 1 was very high acidity as its pH value was 3 and that it was defined as "toxic for all the products". It was observed that the pH value of Soil 2 is 7 (Table 2). In this case, Soil 2 was defined as "all products may grow" in terms of pH value (Table 3). As the pH value of Saharan dust was measured as 7.5, it was observed that it could be classified as "most products may grow" as per Table 3.

When the literature is considered, it has been specified in the studies that the high (7.0 and more) and low (lower than 6.5) degree of the pH value of soil are affecting the plant growth, the effectiveness of plant's nutrient in soil and intake of nutrient by the plants. The pH values required for the optimum growth of each plant are different. However, it has been specified that the maximum intake of most of the nutrients of the plant is being realized at pH values in between 5.5 and 6 [24]. Soil 1 is an infertile soil as its pH is much lower than the normal values, and it can be said that the growth of any plant is impossible on it.

When values in Tables 2 and 3 were compared, it was observed that S1 might be defined as "organic mineral soil" in terms of organic substance and that S2 might be defined as "medium" as per the classification in Table 3.

When the results in Table 4 are examined, it is seen that the Ni concentration determined by TCLP for Soil 1 is very, very low. In a similar manner, the potentially available and immediately available concentrations of Ni in S1 were also very low (Table 4). Fe concentration was determined as 4165±2.20 mg/kg in S1 (Table 2). Considering the TCLP test results, it can be said that a very small part of the Fe determined in S1 is in the form defined as toxic (Table 4). It was observed that the highest concentration among the determined Fe forms was the potentially available form (961.50±0.2 mg/kg) (Table 4). It was observed that 128.30±0.1 mg/kg of the total Cu concentration in S1 was in the toxic form determined by TCLP (Table 4). The total amount of Cd in S1 was measured as 134±0.2 mg/kg (Table 2). It was observed that the Cd concentration, which could be defined in the toxic (TCLP) form, was very low compared to its potentially avaliable and immediately available concentrations (Table 4). When the concentrations of Zn, Pb and Mn in TCLP, potentially and immediately available forms were examined, it was observed that their

Table 2. Characterization of soil and compost samples

Parameter	Unit	Compost	Soil 1	Soil 2	Saharan dust
pH		7.9±0.01	3±0.01	7.00±0.01	7.5±0.01
C	%	11.07±0.001	0.1±0.0002	3.42±0.0001	2±0.0002
N	%	0.28±0.001	ND*	0.545±0.001	0.01±0.001
H	%	ND	0.76	0.95	ND
OM	%	1.36±0.001	28.4±0.02	1.83±0.001	ND
Ni	mg/kg	36±0.002	20.14±0.002	2±0.001	ND
Fe	mg/kg	11000±25.20	4165±2.20	5200±2.50	6.64±0.01
Cu	mg/kg	200±0.3	3515±2.2	48.89±0.02	ND
Cd	mg/kg	1±0.001	134±0.2	ND	ND
Zn	mg/kg	380±0.40	25901±22.55	125±0.2	ND
Pb	mg/kg	80±0.01	3553±1.52	ND	ND
Mn	mg/kg	320±0.15	140±0.22	110±0.20	18.48±0.001

*ND: Not Dedected, ±Standard deviation

Table 3. The relation in between pH degree and growth of products [25] and Classification of soil in terms of organic substance [26]

The relation in between pH degree and growth of products 25			Classification of soil in terms of organic substance 26	
pH	**Reaction of Soil**	**Effect on the Product**	**Organic Substance (%)**	**Classification**
3	Very high acidity	Toxic for all the products	<0.5	Very poor
4	Strong acidity	Toxic for most of the products	0.5–1	Poor
5	Medium acidity	Toxic for some products	1–2	Medium
6	Slight acidity	All the products may grow	2–5	Rich
7	Neutral	All the products may grow	5–10	Very rich
8	Slight alkaline	Most products may grow	10–20	Very much rich
9	Medium alkaline	Toxic for many products	20–50	Organic – mineral soil
10	Strong alkaline	Toxic for all the products		

Table 4. The results of immediately and potentially available elements' experiments and TCLP leaching test for S1

Metal forms	Ni (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Cd (mg/kg)	Zn (mg/kg)	Pb (mg/kg)	Mn (mg/kg)
TCLP (soil 1)	0.1822±0.001	82.40±0.3	128.30±0.1	1.913±0.001	710.50±0.3	39.26±0.01	1.917±0.001
Potentially A.E. (soil 1)	0.7265±0.001	961.50±0.2	440.20±0.2	7.460±0.002	2563.00±22.20	916.00±0.2	5.055±0.001
Immediately A.E. (Soil 1)	0.3788±0.001	143.45±0.3	255.45±0.1	4.745±0.001	1578.50±9.35	66.10±0.01	2.946±0.002

±Standard deviation

concentrations in the form which be assessed as toxic were very low compared to the other forms (Table 4).

When Table 5 was examined, it was observed that the C (%), N (%) and OM (%) contents of both soil samples increased with the addition of compost. With the addition of Saharan dust to the S1 soil sample, it was determined that there was a decrease in the OM (%) value, since OM could not be detected in the Saharan dust (Table 5).

The metal amounts measured in the mixtures in the beakers by the end of the study were given in Table 6. The highest Fe, Zn and Pb concentrations were determined in S1, which was irrigated with Saharan dust water (Table 6). When the results in Table 6 relevant to plant growth were examined, it was observed there was no plant growth in S1, which was irrigated with Saharan dust water. Moreover, it was observed that the pH value of that soil sample was 4.5 (at a pH value being toxic for most of the products) (Table 3). It was determined that the highest Ni and Mn concentrations were in the S2 mixture in which 50% compost was added and which was irrigated with distilled water (Table 6). The highest Cd concentration was measured in S1, which was irrigated with distilled water.

When the pH values measured by the end of the study in the mixtures in beakers were examined, it was observed that the pH value of soil was increasing as per the increasing added compost amount. When Saharan dust was added to S1, it was observed that the pH value of soil was increasing (Table 8). When compost was added to Soil 1, and when it was irrigated with the water obtained from Saharan dust, it was observed that the metals amounts in soil except Ni and Mn were decreasing along with the increase of added compost amount (Table 6). The reason for this is that the amount of Fe and Mn in the Saharan dust is lower than that of S1. Also, Saharan dust does not contain Cu, Cd, Zn, Pb and Ni (Table 2).

Table 5. Nutrient content of mixtures

Sample	C(%)	N (%)	H (%)	OM (%)
S1-C25	2.84	0.07	0.57	21.39
S1-C50	5.59	0.14	0.38	14.88
S1-s25	0.58	0.0025	0.57	21.3
S1-s50	1.05	0.005	0.38	14.2
S2-C25	5.33	0.48	0.71	1.71
S2-C50	4.48	0.41	0.48	1.6
C-s25	8.8	0.21	NM	1.02
C-s50	6.54	0.15	NM	0.68

As a result of the experiments conducted with the S1 sample, it was observed that the concentrations of metals except Ni and Fe were decreasing when compost was added to the S1 sample and when it was irrigated with distilled water (Table 6). This situation may arise from the amount of Ni

Table 6. Metal amounts in soil samples

Sample	Ni (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	Cd (mg/kg)	Zn (mg/kg)	Pb (mg/kg)	Mn (mg/kg)
S1-C0-d	19±0.01	27938±20.20	883±3.45	110±3.45	31800±10.40	4603±12.40	134±11.55
S1-C25-d	18±0.01	26050±12.30	4850±2.80	722±3.45	20338±27.35	3350±18.80	182±9.85
S1-C50-d	20±0.01	30275±11.00	14938±12.25	59±0.02	163623±18.70	2490±5.55	150±3.40
S1-C0-s	19±0.02	34950±15.30	7138±8.60	96±0.01	22275±30.20	4980±25.00	172±1.50
S1-C25-s	30±0.01	31650±32.40	4650±10.30	49±0.01	15688±15.80	3713±14.40	194±7.90
S1-C50-s	32±0.01	26325±25.70	3863±9.85	42±0.02	14263±13.25	3650±9.80	218±4.75
S1-s25-s	26±0.02	24762±22.20	3281±11.15	49±0.01	12881±20.85	3340±6.55	177±3.45
S1-s50-s	16±0.01	16268±22.20	1422±7.45	15±0.01	6899±13.45	1450±3.40	132±10.05
S2-C0-d	ND	5155±9.15	33±0.01	ND	111±5.45	ND	57±0.01
S2-C25-d	24±0.01	6235±13.35	154±5.05	ND	322±3.85	501±4.95	231±12.20
S2-C50-d	44±0.01	10868±17.40	159±3.45	ND	327±4.45	79±0.01	295±17.40
S2-C0-s	ND	1585±8.45	38±0.01	ND	162±8.90	4.5±0.01	49±0.01
S2-C25-s	34±0.01	8648±3.50	144±6.70	ND	278±12.40	70±0.01	278±13.35
S2-C50-s	29±0.02	7833±9.80	146±9.80	ND	787±18.50	42±0.01	259±16.55
C-s0-d	35±0.01	10800±20.00	200±7.40	ND	378±4.20	77±0.02	312±8.40
C-s25-d	34±0.01	8988±18.50	109±6.50	ND	325±2.80	56±0.01	239±4.40
C-s50-d	33±0.02	9788±14.40	76±2.50	ND	212±3.65	46±0.01	200±8.75
s100-d	17±0.01	4725±5.50	4.5±0.2	ND	145±6.40	20±0.01	97±0.01

±Standard deviation

and Fe in compost being higher than the amount of compost samples (Table 2). When Saharan dust was mixed with S1, and when it was irrigated with water obtained from Saharan dust, it was observed that the concentrations in the soil of all the metals were decreasing once the amount of Saharan dust added to S1 increases (Table 6). The finding suggests that the cause of it may be that these metals in the Saharan dust are either in very few amounts or not even available (Table 2). When S1 soil containing heavy metals in high concentrations and S2 soil, which is suitable soil for plantation, were examined concerning the metal concentrations they contain, it was seen that there is a statistically significant difference between the concentrations of Fe, Cu, Cd, Zn, Pb metals ($p < 0.05$). When the two soil types were compared, there was no statistically significant difference between the Mn concentrations in the soils ($p > 0.05$). After the growth of the plants, the metal concentrations in them were examined according to the soil type they grow in, and a statistically significant difference was found in Fe, Cu, and Zn concentrations among the plants grown in different soil types ($p < 0.05$).

As a result of the measurement of metal concentrations in plants, it was observed that the metal amounts in the plant were decreasing (expect Ni and Pb) as the added amount of Saharan dust increases. These results were similar to the results measured in S1 and Saharan dust mixtures (Table 6 and 7). When Table 7 is examined, it was observed that while the pH of Soil 1 was 3, it was reaching to pH values of 6–7 by the addition of compost. In the same manner, it was observed that again pH values of 6–7 were reached when Saharan dust was added to S1 (Table 8). It has been provided in the literature that a suitable pH value for the growth of green bean plant is 5.5–6.7 [27]. For this reason, it is being thought that the green bean plant is unable to grow in soils and soil mixtures where the pH is 5 and less.

When metal amounts measured in the plant were considered, it was observed that the green bean plant did not grow in beakers containing only S1 (both when irrigated with distilled water, and when irrigated with water obtained from Saharan dust). It was observed that plant growth was realized by the addition of compost to S1. When 50% (v/v) compost was added to Soil 1, and when irrigation was made with the water obtained from Saharan dust, it was observed that the growth of plant is much better compared to irrigation with distilled water (while 6 cm plant height and about 1 gr plant weight were measured in irrigation with distilled water, 20 cm plant height and about 2 gr plant weight was measured as the result of irrigation with water obtained from Saharan dust) (Table 8). Depending on the soil type, a statistically significant difference was found in the growth of plants in different soil types (only when evaluated concerning plant height) ($p < 0.05$). When S1 was mixed with Saharan dust at ratios of 25% (v/v) and 50% (v/v), and when irrigation was made with the water obtained from

Table 7. Metal amounts in plant samples

Sample	Ni (mg/kg)	Fe(mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Pb (mg/kg)	Mn (mg/kg)
S1-C0-d			The plant did not grow.			
S1-C25-d	1.25±0.001	288±10.55	54±0.01	2428±20.85	13±0.01	172±4.80
S1-C50-d	19±0.01	332±4.40	61±0.01	273±5.55	40±0.01	120±3.60
S1-C0-s			The plant did not grow.			
S1-C25-s			The plant did not grow.			
S1-C50-s	1.5±0.001	370±8.90	181±4.45	886±6.75	131±15.50	126±9.45
S1-s25-s	13±0.01	585±4.70	85±0.01	361±4.50	ND	83±0.01
S1-s50-s	14±0.01	327±2.35	40±0.02	212±2.80	19±0.01	77±0.01
S2-C0-d	1.25±0.002	167±6.60	27±0.02	125±4.85	ND	100±10.55
S2-C25-d	11±0.02	227±4.30	36±0.01	222±3.45	ND	78±0.01
S2-C50-d	19±0.01	184±3.40	40±0.01	179±5.50	ND	93±0.01
S2-C0-s	ND	191±1.25	20±0.01	175±6.80	5.5±0.001	94±0.02
S2-C25-s	13±0.01	161±5.50	25±0.02	138±4.40	ND	56±0.01
S2-C50-s	7.3±0.001	201±6.80	30±0.01	191±3.60	5.1±0.001	56±0.01
C-s0-d	13±0.01	196±12.80	19±0.01	107±12.80	78±0.01	38±0.02
C-s25-d	5.75±0.001	253±17.40	21±0.02	151±15.00	ND	46±0.02
C-s50-d	6.5±0.001	159±5.65	23±0.02	139±14.90	ND	53±0.01
s100-d	8.75±0.001	184±3.90	26±0.02	100±10.00	85±0.01	34±0.01

ND:not dedected ±Standard deviation

Saharan dust, it was observed that values similar to ones in which 50% (v/v) compost was used were obtained in terms of plants' height and weight (Table 8). However, when the comparison was made according to the type of irrigation (what the plants were irrigated with) ($p > 0.05$), a statistically significant difference could not be found between the level of growth and the heavy metal concentrations in the plants.

In experiments in which S2 was used, it was observed that all the metal concentrations in soil were increasing along with the increase of compost amount added to S2 and when irrigation was made with distilled water. When compost was added, and irrigation was made with the water obtained from Saharan dust, it was observed that lower amounts of the increase were occurring compared to irrigation with distilled water despite the increase of metal concentrations in soil along with the increase of added compost amount (Table 6). It was observed that the growth of plant was worsening when irrigation was made with distilled water as the compost amount added to the S2 sample increases. When irrigation was made with water obtained from Saharan dust, it was again observed that the best plant growth was in the sample in which compost was not added. However, it was determined that addition of 50% (v/v) compost was yielding to better results in terms of plant growth compared to the addition of 25% (v/v) compost (Table 8).

It was determined that Ni and Cu amounts in the plant were increasing in irrigation with distilled water as the amount of compost added to S2 increases and that Fe and Zn were at higher values in the plant samples growing in S2 in which 25% (v/v) compost was added compared to other soil samples (Table 7). There are many studies in the literature in which compost has positive effects on the growth of plant [12, 13, 28]. Moreover, there are studies in the literature regarding the usability of compost in the remediation of soils which are contaminated with heavy metals or which have high heavy metal content [13, 19, 29, 30]. Desert dust is nutrimental for some plants, but it is not being possible to say that all desert dust is nutrimental at the same level. Even the desert soil, which gets wet with the rains and enters the soil, enriches the soil, bacteria and mushrooms, increases the fertility of the soil and acts as an almost natural fertilizer [16]. In laboratory environment, dust and sands from different desert areas were compared by Saydam (2002) [22], and it was determined that Saharan dust was the most fertile among them. When studies in the literature are considered, there are studies which specify that water obtained from Saharan dust has positive effects in growing plants as if like a fertilizer [16, 17]. When the results in Tables 5, 6 and 7 are examined, it is being seen that the compost and Saharan dust and that the solution obtained by diluting the Saharan dust are enabling remediation in soil containing high amounts of

Table 8. pH values of samples by the end of the study, and heights and weights of plants

Sample	pH	Plant Height (cm)	Plant Weight (gr)
S1-C0-d	3	The plant did not grow.	The plant did not grow.
S1-C25-d	6	5	1.978
S1-C50-d	7	6	0.978
S1-C0-s	4.5	The plant did not grow.	The plant did not grow.
S1-C25-s	5	The plant did not grow.	The plant did not grow.
S1-C50-s	6	20	1.830
S1-s25-s	5	19	1.750
S1-s50-s	6	20.5	1.600
S2-C0-d	6	22	1.978
S2-C25-d	6	7.5	0.920
S2-C50-d	6	7.6	0.970
S2-C0-s	7	34	2.550
S2-C25-s	7.2	18.75	1.688
S2-C50-s	7.4	23	2.288
C-s0-d	8	2	0.724
C-s25-d	7.8	2	0.647
C-s50-d	7.6	6	0.821
s100-d	7.5	1	0.753

metal and having an acidic character. It has been observed that the compost and Saharan dust and that the solution obtained by diluting the Saharan dust affects the plant growth positively and leads to a decrease in the amount of heavy metals penetrating the plant.

CONCLUSIONS

In this study, the effects of using the solution obtained by diluting Saharan dust and Saharan dust as a soil conditioner on the development of the bean plant were investigated. At the same time, the change in the amount of metal passing from soil to plant was also investigated. It was worked under the same conditions with the commercially sold S2 for the purpose of control. Moreover, the effects of irrigation with distilled water and irrigation with water obtained from Saharan dust on the plant growth and the penetration of metals to the plant were examined. It was observed that no plant growth occurred when no remediation was made on S1. It was observed that the best plant growth for S1 was occurring in mixtures in which Saharan dust was added and which were irrigated with water obtained from Saharan dust. When metal amounts penetrating the plant was considered, lower metal concentrations were determined in the plants growing with mixtures in which Saharan dust was added and which were irrigated with Saharan dust water compared to mixtures in which compost was added and which were irrigated with Saharan dust water. In the experiments, it was observed that in the soil in which 50% Saharan dust was added, although the amount of the Saharan dust added was increased, the amount of Ni and Pb transferred to the growing plants increased. With the addition of the Saharan dust, the heavy metal concentrations in the soil decreased in proportion to the amount of the Saharan dust added (there is considered to be a decrease due to the dilution in the metal density in the soil). Despite this observation, there was no decrease in the amount of metal transferred from the soil to the plant consistent with the decrease in the metal ratio in the soil. This circumstance shows us that although the heavy metal concentrations in the soil decreased due to dilution as a result of the addition of the Saharan dust to the soil, this dilution was not effective in the metal concentrations detected in the plant. Also in the control sample, it was observed that plant growth was better in soils irrigated with water obtained from Saharan dust. Moreover, the metal concentrations determined in plants growing in beakers containing control soil (S2) which were irrigated with water obtained from Saharan dust are lower than the metal concentrations determined in plants growing in beakers which were irrigated with distilled water. It was observed that irrigation with Saharan dust water and/or addition of Saharan dust was making S1 suitable for the growth of plant by increasing its pH in a similar way as adding compost.

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DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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