Phytoremediation efficiency of the Sunflower Plant (*Helianthus annuus* L.) in Soil contaminated with Multiple Heavy Metals

Seren Yavaş Bölükbaşı and Bülent Topcuoğlu

Abstract**—** This study investigated the effect of multiple metals (Zn, Cu, Ni, Pb, and Cd) applied to soil on the phytoremediation efficiency of the sunflower (Helianthus annuus L.) plant. The application of multiple metals caused a significant decrease in the growth and biomass of the sunflower plant. Metal accumulation in the sunflower plant varied between the roots and the aerial parts depending on the element. The highest metal uptake value was recorded for Zn, while the highest uptake values for Cu, Zn, Ni, and Cd were determined in the aerial parts. The highest bioconcentration factor values in the sunflower plant were determined for Cu, Zn, and Pb. In terms of phytoremediation efficiency, the highest values for Zn and Cd were observed in the shoot parts of the sunflower plant. It is estimated that phytoremediation using sunflowers in metal-contaminated soil could be significantly effective in reducing metal concentrations in the soil.

Index Terms**—** Phytoremediation, heavy metals, sunflower
Introduction

1. INTRODUCTION

Soil contamination reaching harmful levels can lead to the accumulation of pollutants in the tissues of plants growing in the soil, thereby increasingly affecting organisms that consume these plants as animal feed or food, and causing irreversible damage to the ecosystem [1]. The most significant pollutants in terms of soil contamination are heavy metals. Heavy metals tend to accumulate in soil, sediment, freshwater sources, or seawater. Because they are released into the atmosphere from various sources and, as a result of dry or wet deposition, enter the soil, surface waters, and ultimately groundwater—causing serious ecological damage—they are of great importance in terms of environmental pollution [2].

Since heavy metals such as Pb, Cd, As, and Hg serve no function in plants, they have toxic effects at any concentration level [3]. The toxic effect of these metals is closely related to their concentration in the environment in their dissolved form. When the concentration of heavy metals exceeds a certain level, it poses a threat to life not only in the soil but throughout entire ecosystems. Because they cannot be biologically degraded, heavy metals can enter the food chain through cultivated plants and, ultimately, accumulate in the human body through bioaccumulation [4].

Hyperaccumulator plants are plants capable of actively taking up one or more heavy metals from the soil, accumulating 100 to 1,000 times more metal in their aboveground parts than the metal concentration in the soil, and yet showing no signs of phytotoxicity. In phytoremediation, hyperaccumulator plants are used to decontaminate soil of pollutants, and the primary strategy involves identifying plants found in nature that possess high biomass and the ability to accumulate excessive amounts of metals [5].

The objective of this study was to determine the phytoremediation efficacy of sunflowers in soil contaminated with multiple metals.

II. MATERIALS AND METHODS

A. Experimental Soil and Growing Conditions

The study was conducted as a pot experiment in a ventilated, light-controlled glass greenhouse at Akdeniz University. Red Mediterranean soil, which is common in the Mediterranean Region, was used in the experiment. The experimental soil was air-dried and sieved through a 2-mm sieve before being prepared for the experiment. The analytical characteristics of the experimental soil are presented in Table 1.

TABLE 1. ANALYTICAL CHARACTERISTICS OF THE CONTROL SOIL IN THE EXPERIMENT

Parameters	Data	Soil metal limits (mg kg -1
pH- H 2 O (1:2,5 w/v)	7.78	
Electrical Conductivity	0,775	
CaCO3, %	10,2	
Organic matter, %	1,88	
Texture	Clay loam	
Cation Exchange	19,5	
Total Zn, mg kg $^{-1}$	29	150-300
Total Cu, mg kg $^{-1}$	2,2	140
Total Pb, mg kg $^{-1}$	3,4	300
Total Ni, mg kg $^{-1}$	3,2	75
Total Cd, mg kg $^{-1}$	<0,001	3

The original properties and metal contents of the experimental soil are within acceptable limits, and the soil is classified as clean.

In the experiment, each pot was filled with 10 kg of air-dry soil, and basal fertilization was applied using $NH_4 NO_3$, $KH_2 PO_4$, and $K_2 SO_4$ to provide N, P, and K levels of 70, 35, and 70 mg kg^{-1}, respectively. Both control and

Manuscript received October 28, 2026.

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metal-treated treatments were included in the experiment, and the experimental design is presented in Table 2. Additionally, 100 mg kg^{-1} of humic acid was applied to all pots, and the soils were incubated at field capacity for at least one month. Following incubation, oilseed sunflower was grown as the phytoremediation plant in the experiment. The experiment was conducted using a factorial design with 5 replicates in a randomized block design. In the experiment, two sunflower plants were grown in each pot for 60 days and harvested by cutting them at soil level at the end of the experiment. After harvest, the roots of the plants in the pots were carefully washed to separate them from soil particles.

TABLE II. CONCENTRATIONS OF HEAVY METALS APPLIED TO THE POTTING SOILS IN THE EXPERIMENT

Metals	Control, mg kg^{-1}	Metal treatments mg kg^{-1}
Zn	0	300
Cu	0	140
Ni	0	75
Pb	0	300
Cd	0	3

B. Plant Analyses

The shoot and root biomass values of the harvested plant samples were determined by weighing. Fresh plant samples were washed and rinsed in distilled water, then dried at 65 °C to determine their dry matter content. The dried plant samples were subsequently ground in a porcelain mortar. The ground plant samples were wet-ashed in an aqua regia mixture (1:3 HNO_3 /HCl), and the resulting solution was analyzed to determine the total concentrations of Zn, Cu, Ni, Pb, and Cd using an ICP-MS instrument under optimized measurement conditions, in accordance with the analytical procedure, through a contracted service [7].

C. Phytoremediation evaluation parameters

Bioconcentration factor (BCF): This index indicates the degree to which metals in the soil are transferred to the plant's aboveground parts. The bioconcentration factor (BCF) is calculated as shown in below equation[8]:

$$BCF = \frac{C_{Plant}}{C_{Soil}}$$

C_(Plant): Total metal concentration in the plant on a dry weight basis,
C_(Soil): Total metal concentration in the soil on a dry weight basis.

Theoretical total metal uptake: Represents the metals extracted by the plant from a unit of soil until harvest and is calculated as shown in below equation [9]:

$$Metal\ uptake\ \left(\frac{mg}{pot}\right) = C \times W \times n$$

C: heavy metal concentration in plant tissue (mg kg^{-1} dry weight),
W: plant dry weight (kg $plant^{-1}$),
n: number of plants.

Theoretical phytoextraction efficiency (%): This represents the proportional level of metals extracted from the soil by the plant and is calculated as shown in below equation [10]:

$$Phytoextraction\ efficiency\ (\%) = \frac{Cp \times W \times n}{Cs \times Soil\ amount\ \left(\frac{Soil}{Pot}\right)}$$

Cp: heavy metal concentration in plant tissue (mg kg^{-1} dry weight);
W: plant dry weight (kg pot^{-1});
N: number of plants;
Cs: metal concentration in soil (mg kg^{-1}).

Statistical Analyses

Analysis of variance (ANOVA) and descriptive statistical analyses were performed using SPSS 23 to compare differences in the parameters.

III. RESULTS AND DISCUSSION

The application of heavy metals to the soil had a significant effect on the fresh and dry matter contents and plant height of sunflower plants, and the plants' physical growth parameters decreased with metal application (Figure 1). This decline in sunflower plant growth observed with multiple metal applications suggests that the metals have toxic effects on plant growth.

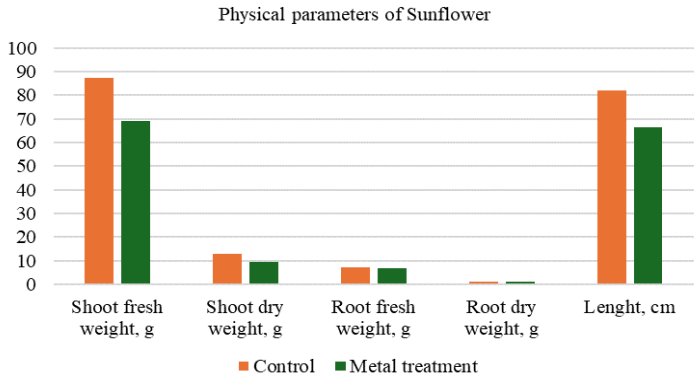


Fig. 1. Average values of the physical parameters of sunflower plants in the control and metal application treatments

The metal contents of the sunflower plants followed the order Zn> Ni> Cu> Pb> Cd, respectively. As expected, higher metal contents were observed in the sunflower plants in the metal application treatments compared to the control treatment (Figure 2).

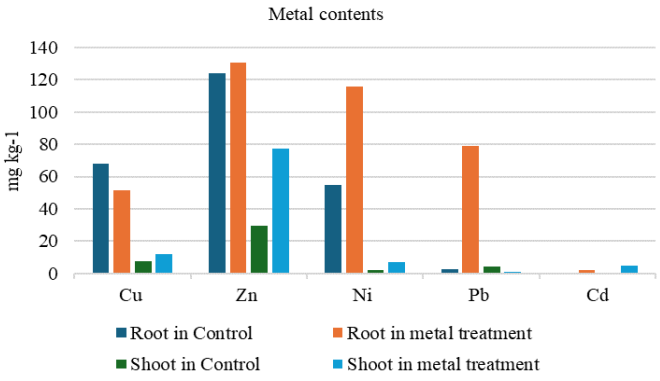


Fig. 2. Metal contents in the roots and shoot tips of sunflower plants in control and metal-treated treatments

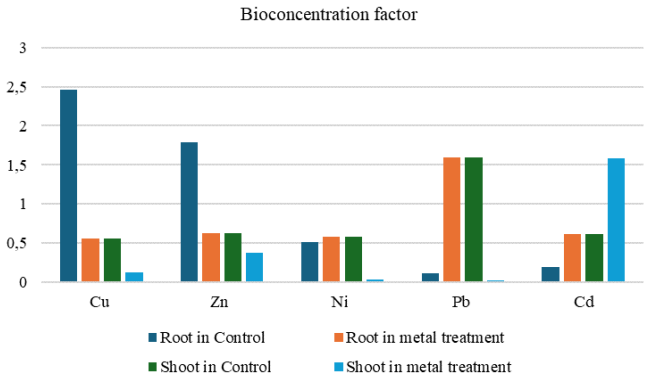


Fig. 3. Bioconcentration factors in the roots and shoot parts of the sunflower plant in control and metal-treated treatments

The highest metal uptake values in sunflower plants were recorded for Zn, Cu, Ni, and Pb. The highest metal uptake values for Cu, Zn, Ni, and Cd were determined in the shoot (Figure 3). It has been reported that metal uptake values in sunflower plants are high for Zn, Cu, and Pb, with the highest uptake value observed for Zn [11,12].

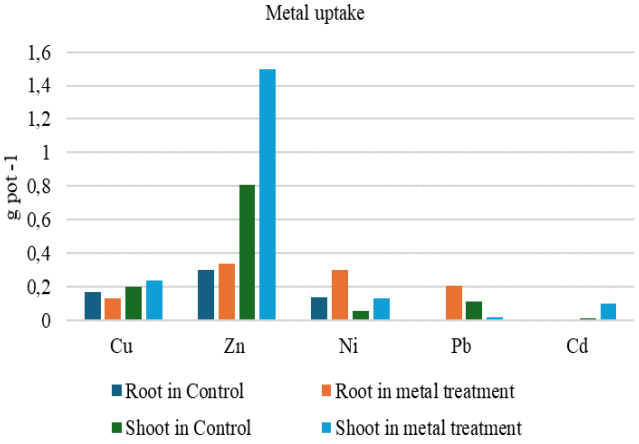


Figure 4. Metal uptake values in the roots and shoot parts of sunflower plants in control and metal-treated treatments

The highest BCF values in sunflower plants were observed for Cu, Zn, and Pb. In general, the BCF values of sunflower plants were higher in the shoot parts. The BCF value for Cd was found to be higher in the aboveground parts of the sunflower plant. In studies evaluating the phytoremediation effectiveness of plants, a BCF value greater than 1 indicates that the plant is suitable for phytoremediation [13]. In terms of phytoremediation effectiveness, the highest BCF values for the sunflower plant were determined for Pb and Cd in the metal application treatments. In this regard, it has been reported that the BCF values for Zn, Cu, and Cd in sunflowers are higher than those for other metals; that sunflowers absorb high amounts of Zn, Cu, and Cd from the soil; and that the highest BCF value was determined for Cd [12].

In terms of phytoremediation efficiency, the shoot parts of the sunflower plant were found to exhibit the highest values for Zn and Cd. The PE values for Zn and Cd in the sunflower plant were found to be higher in the shoot parts. A higher PE value for Pb was determined in the roots of the sunflower plant (Figure 4). The highest PE value in the sunflower plant was determined for Cd. Studies on this subject have reported that the sunflower plant has a high tolerance to heavy metals [14], that the highest bioaccumulation and BCF values in the sunflower plant were determined for Cd [15], and that the sunflower plant possesses a high phytoextraction capacity in contaminated soils [16].

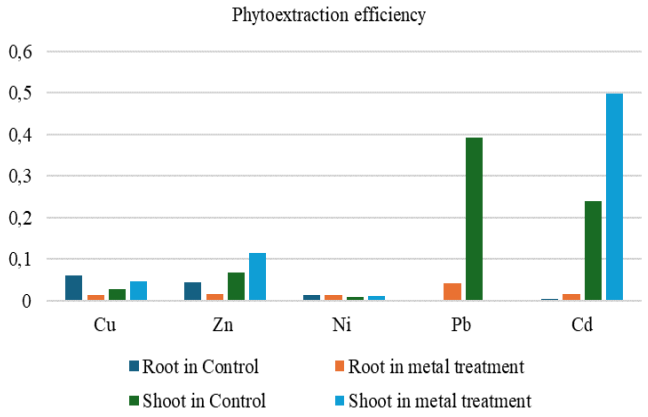


Fig. 5. PE (phytoextraction efficiency) values in the roots and shoot organs of sunflower plants under control and metal-treated conditions

IV. CONCLUSION

It was found that metal applications caused a significant decrease in the growth and biomass of the sunflower plant. This study demonstrated that, in a multi-metal application containing Cu, Ni, Zn, Cd, and Pb, metal accumulation varied between the roots and shoot organs depending on the element. The highest metal uptake value was recorded for Zn. The highest metal uptake values for Cu, Zn, Ni, and Cd were determined in the shoot. The highest BCF values in the sunflower plant were determined for Cu, Zn, and Pb. In terms of phytoremediation efficiency, the sunflower plant’s shoot parts exhibited the highest values for Zn and Cd. These findings suggest that phytoremediation using sunflowers in

metal-contaminated soil could be significantly effective in reducing metal concentrations in the soil.

ACKNOWLEDGMENT

This study is based on the thesis project of Seren Yavaş, a master’s student who completed her thesis under the supervision of Prof. Dr. Bülent Topcuoğlu at the Department of Sustainable Agriculture, Institute of Natural Sciences, Akdeniz University. The authors would like to thank the administrative and technical staff at Akdeniz University for supporting this project (FYL-2024-6605).

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