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Employing Phytoremediation Methods to Extract Heavy Metals from Polluted Soils

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ABSTRACT

The phytoremediation technique has become very efficient for treating soil contaminated with heavy metals. In this study, a pot experiment was conducted where the *Dodonaea* plant (known as hops) was grown, and soil previously contaminated with metals (Zn, Ni, Cd) was added at concentrations 100, 50, 0 mg·kg^{-1} for Ni and Zn, and at concentrations of 0, 5, 10 mg·kg^{-1} for cadmium. Irrigation was done within the limits of the field capacity of the soil. Cadmium, nickel and zinc was estimated in the soil to find out the capacity of plants to the absorption of heavy and contaminated metals by using bioconcentration factors (BCFs), bioaccumulation coefficient (BAC) and translocation factor (TF). Additionally, BCF values of both Ni and Zn were less than one i.e. *Dodonaea* hazing moderate bioaccumulation properties based on heavy metals. As for BCF values of Cd, they have by passed, i.e. *Dodonaea* has the ability to the absorption of cadmium sulfate in the root system. Regarding the bioaccumulation coefficient (BAC) values for Cd, Ni, and Zn, it was found that they were generally below one, indicating that Dodonaea exhibits moderate capabilities for bioaccumulating these heavy metals. Therefore, *Dodonaea* plant is useful in treating heavy metals. Highlighting a pioneering approach, this study introduces a novel method that significantly advances the understanding of phytoremediation's role in reducing pollution caused by various industries working on the soil, specifically through the use of *Dodonaea* in the T3 treatment group, which showed remarkable efficacy on metal-contaminated soil.

Keywords: heavy metals, bioaccumulation coefficient, contaminated soils, environmental pollution.

INTRODUCTION

The problem of environmental pollution is one of the most important problems that has taken on social dimensions, especially after industrial expansion supported by modern technologies. Industries have recently taken dangerous trends represented by the great diversity of industries, especially complex ones (Ozyigit et al., 2022), which are accompanied by serious pollution that leads to the deterioration of the biosphere and the elimination of the natural environment system. Environmental scientists have differed in finding an accurate definition of environmental pollution. However, the concept of pollution is linked primarily to the environmental system, as the quantitative or qualitative change that occurs in the elements of this system leads to disruption in it (Kumari et al., 2022). The tremendous development witnessed by the world and the industrial revolution led to the infliction of a lot of damage to the components of the environment as a result of their contamination with many pollutants, including heavy elements (Zalan et al., 2006). Heavy metals are among the most dangerous pollutants released into the environment, and their danger increases when they remain in the soil or undergo any chemical changes and lead to the contamination of plants, fruits and vegetables that humans eat, which is reflected in their health (Li et al., 2023). Heavy metals, defined chemically as metals and metalloids with atomic masses above 20 and specific gravities over 5 g·cm^{-3}, are biologically harmful to plants even in minimal quantities, as stated by Li et al., 2019. These persistent and non-degradable pollutants significantly alter the structure, diversity, and function of ecosystems, posing serious threats to environmental health, agriculture, and wildlife, as described by Younas et al. (2022), and Iqbal et al. (2023). Nkoh et al. (2022) found that soil pollution increases the level of metals in ecosystems, and Kumari et al., 2022 and Iqbal et al., 2023 found effect of some heavy metals on organisms, crops, soil and human health. While some heavy metals like copper, zinc, chromium, iron, nickel, and manganese are essential for plant growth functions, as Lajayer et al. (2019) notes, others such as cd, pb may not be inherently toxic but still impact plant health, according to Ahmad et al. (2023). The toxicity, persistence, ability to bioaccumulate, and non-biodegradability of heavy metals mark them as notable environmental pollutants, as discussed by Usman (2022) and Jehan et al. (2021). In a study conducted by (Yerima et al., 2023), it was found that pharmaceutical production processes add heavy elements and that the sandy layer of the soil reduces the relative immobility due to pH and organic matter. Anayat et al. (2014) studied the effect of mercury and cadmium on the growth of the sweet bean plant (*Foeniculum vulgare*) by adopting different concentrations and indicated that the effect of mercury was higher than the effect of cadmium on the plant, and that the leaf area was affected with accumulation or elements.

Phytoremediation refers in particular to the ability of plants to treat, as some plants have developed their remove some pollutants from the soil or restrict their movement in the soil or water through their biological, chemical and physical activity or as a result of the nature of their adaptation to living in soil. Contaminated with heavy metals and includes the ability to absorb and regulate the distribution of elements within plant tissues (Sharma et al., 2023). Goel et al. (2009) defined bioremediation or bioremediation (phytoremediation) as the processes carried out by plants to decrease toxic and heavy elements from soil and water. Mudgel et al. (2010) called (phytoremediation) green technology, which is the method by which concentrations of pollutants are reduced. In the soil through absorption by cultivated plants, which is an excellent way to remove and clean pollutants from the soil. Lahori et al. (2023) conducted a study to examine the individual effect of clay fertilizer and a compound on fixing lead and cadmium in contaminated soil. The results indicated that compaction of clay fertilizer alone and a compound had a positive effect on plant growth and immobilize cd and pbin soils and reduced the absorption of lead and cadmium by sorghum. It was also found (Wu et al., 2024) that biochemical factors and mechanisms affect the plant's absorption of heavy elements in the presence of microplastics (Mps), which extend from the soil to the roots and are transported by absorption. It has been found that Mps contribute to the removal of heavy elements from the soil through the plant. This study aims to provide new insights into the health risks of heavy metal accumulation and the ability of the Didonia plant to absorb heavy metals and pollutants using TF, BAC, and BCFs.

MATERIALS AND METHODS

Study area

The experiment was carried out in the wooden canopy of the Plant Agriculture Department located in the Al-Qadisiyah region in the 2022–2023 season, as a suitable space was allocated to place the plastic pots and provide all the supplies for the experiment.

Experiment

The pots experiment of the present study was conducted in Al-Qadisiyah province. The soil samples have been taken from 0–30 cm of College of Agriculture soil, these samples are required to be air dried (soil is dried by air drying technique), the samples passed through the No. 4 sieve (4 mm diameter), then the samples were filled in 10 kg of soil in plastic plant pots where the soil was previously contaminated with heavy metals cadmium (Cd), nickel (Ni) and zinc (Zn), which prepared as homogeneous precipitations such as (zinc sulfate, nickel sulfate and cadmium sulfate) as the quantity was designed according to the concentrations used for both nickel (Ni) and zinc (Zn) (0, 50 and 100 mg·kg^{-1}) and (0, 5 and 10 mg·kg^{-1}) for cadmium (Cd) elements (T_1, T_2 and T_3), so the number of experiment units become 9. Hence, these three heavy metals were mixed in with soil before planting, and then water was added to the soil within the limits of field capacity (FC). The samples were left more than 20 days for the purpose of balancing and planting *Dodonaea* (known as *hop-bushes*), which were obtained in the form of small seedlings that were taken from nurseries in the city of Diwaniyah in November 20th, 2022. Additionally, add water for irrigation and then NPK (nitrogen, phosphorus, and potassium) fertilizer was added according to fertilizer recommendation.

Laboratory analysis

The samples are required to be air dried (soil is dried by air drying technique), then soil has been ground to a two particles; the first soil particle passes the No. 10 sieve (2 mm diameter) in order to make the following physical and chemical analyses:

a) soil particle size distribution: it is used to estimate soil particle size distribution according to Piper (2019),
b) soil reaction rate has been measured by using pH-meter, as for the electrical conductivity (EC) can be measured using a meter and probe as well (electrical conductivity bridge),
c) the organic carbon of sample has been estimated according to the Walkley-Black method described in Piper (2019).

As concerning the second soil particle that has been prepared to estimate heavy metals (cadmium, nickel and zinc) according to (Jones' et al., 2001) all the fluids have measured using atomic absorption spectroscopy (AAS). And then heavy metals (cadmium, nickel and zinc) in soil has been calculate the pots experiment in April 20th, 2023. At first, the root-shoot systems of *Dodonaea* washed by using tap water, then the root-shoot systems of *Dodonaea* washed using distilled water and finally the root-shoot systems of *Dodonaea* have dried and crushed and then Digestion in order to see the absorption of heavy and contaminated metals as a focus of phytoremediation according to plant contamination criterions using (Rafati's et al., 2011) (Table 1).

1. Bioconcentration factor (BCF):

$$\mathrm{BCF} = \frac{[Metal]_{Root}}{[Metal]_{Soil}} \quad (1)$$

2. Bioaccumulation coefficient (BAC)

$$\mathrm{BAC} = \frac{[Metal]_{Shoot}}{[Metal]_{Soil}} \quad (2)$$

3. Translocation factor (TF)

$$\mathrm{TF} = \frac{[Metal]_{Shoot}}{[Metal]_{Root}} \quad (3)$$

STATISTICAL ANALYSIS

The results of the present study have been analyzed statistically; the experiment is conducted using three rates and according to CRD, and then the treatment means are compared with the LSD at level 5 percent by using Microsoft Excel Program.

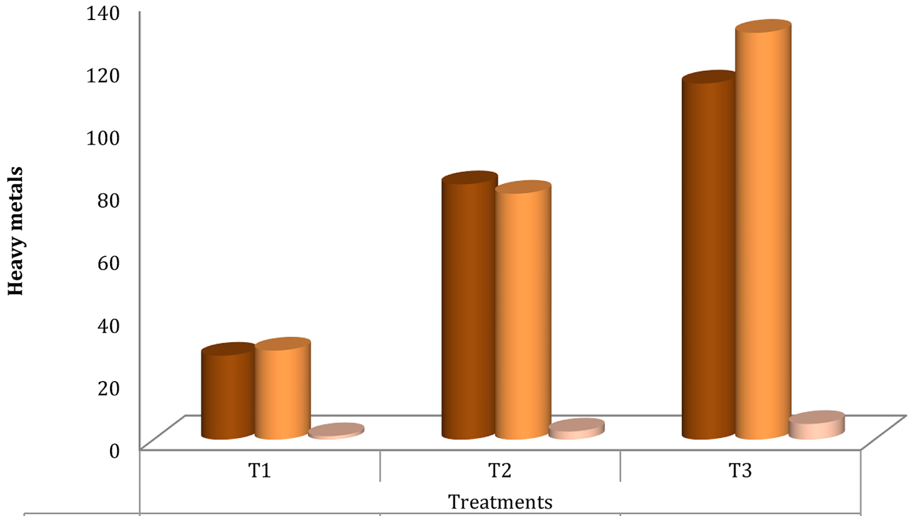
RESULTS AND DISCUSSION

Soil

Figure 1 refers to the total heavy metals (nickel, cadmium and zinc) in soil after the experimental biology that lasted about more than five months, which is *Dodonaea*. Figure 1 shows heavy metals has significantly increased with increasing levels of addition. T_3 was the highest

Table 1. Some soil characteristic for study are

Analysis		Value	Units
Electrical conductivity 1:1		4.8	dS m^{-1}
pH soil 1:1		7.90	/
CEC		18.20	Cmol + kg^{-1}
O.M		9.00	gm·kg^{-1}
$CaCO_3$		247.00	
Total Zn^{+2}		54.63	mg·kg^{-1}
Total Ni^{+2}		60.74	
Total Cd^{+2}		2.10	
Soil particles	sand	70.00	gm·kg^{-1} soil
	silt	70.00	
	clay	860.00	
Textural class		clay loam	/
Water content at 330 kPa		0.31	cm^3 cm^{-3}



	T1	T2	T3
Zinc	26,86	81,65	113,82
Nickel	28,49	78,65	130
Cadmium	1,11	2,6	5,03

Figure 1. Total concentration in study soil after biological experiment (mg·kg^{-1})

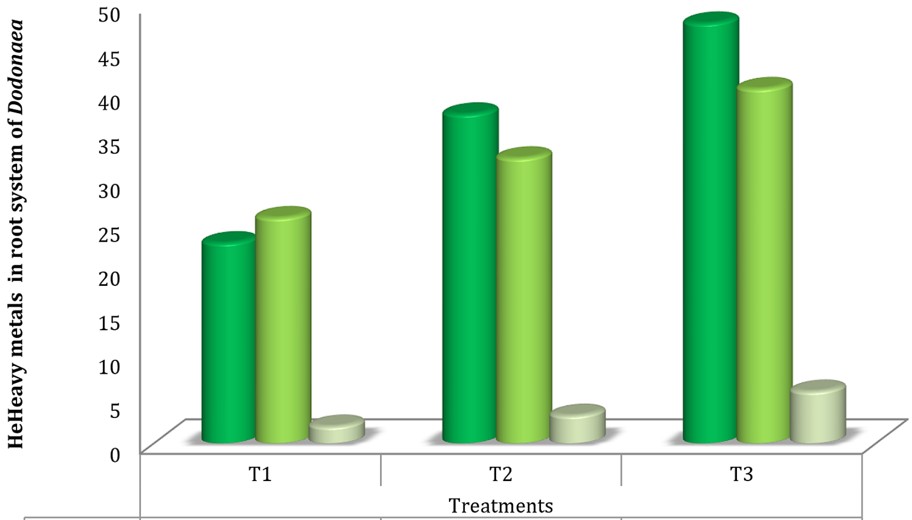
concentration in level of zinc sulfate, nickel sulfate and cadmium sulfate that were 113.82, 130.00 and 6.09 sequentially, whereas the comparison of T_1 values was equal to 26.86, 28.49, and 1.11 of soil for each of cadmium, nickel and zinc sequentially. So when comparing Zn concentration with the parameters of the (FAO) and (WHO), we find that these parameters are within the possible limits are 300 mg·kg^{-1} of soil. As concerning with Cd and Ni were exceeded the allowable limit of 50 and 3 mg·kg^{-1} of soil excluding the comparison treatment (WHO and FAO, 2007). So when scomparing the heavy metals we found (cadmium, nickel and zinc) of the study sample (soil) before planting that were 54.63, 60.74, and 2.10 mg·kg^{-1} for each of Zn, Ni and Cd sequentially with the comparison sample after planting, noticing that there is an decrease in total concentration of heavy metals, which refers to the ability to the absorption of heavy and contaminated metals (cadmium, nickel and zinc) that is in line with Mudgel et al., 2010 by using green technology (also known as environmental technology or clean technology), as the concentrations in the soil decrease by being absorbed by cultivated plants, this green technology that involved "tolerant plants". This is consistent with the findings of Harati et al. (2011) when they studied the effect of heavy elements added to the soil on the pollution of agricultural lands located in southern Tehran resulting from the addition of heavy elements or irrigation with wastewater. The results indicated the accumulation of heavy elements in high concentrations in soil planted with plants, especially cadmium.

Heavy metals in *Dodonaea*

Heavy metal in root of Dodonaea

Figure 2 show heavy metals (zinc, nickel and cadmium) of root of *Dodonaea*. So, statistical analysis shows that there were significant differences in the concentration of heavy metals under study. So, T_3 was significantly superior to the others, which was 47.79, 40.35 and 5.92 mg·kg^{-1} dry matter respectively, with T_1, which was to 22.83, 25.69 and 1.93 mg·kg^{-1} respectively. It can be noted that nickel and zinc did not go above allowed limits that were prepared by FAO and WHO, which were 60 and 67 mg·kg^{-1} for both zinc and nickel respectively. As concerning cadmium, all treatments exceeded the allowed limits of concentrations of 0.30 mg Cd (WHO and FAO, 2007).

The findings indicate a direct correlation between the rise in heavy metals in the soil and their uptake by plants through the roots. These results align with the observations made by Smiljanic et al. (2019), which noted that an increase in soil is accompanied by a corresponding increase in their levels within the soil. This is consistent with what was stated by Kebir and Bouhadjera (2011) as their results indicated the ability to absorb heavy elements from contaminated soil resulting from adding heavy elements to the soil and increasing their



	T1	T2	T3
Zinc	22,83	37,46	47,79
Nickel	25,69	32,47	40,35
Cadmium	1,93	3,17	5,92

Figure 2. Heavy metals concentration in root system of *Dodonaea* after experiment (mg·kg^{-1})

ready concentrations, increases accumulation of levels of these metals in the root, vegetative system of the plant.

Heavy metal in the shoot system of Dodonaea

Figure 3 show that significant differences of heavy metals (zinc, nickel and cadmium) of the shoot system of *Dodonaea*. So, T_3 was significantly superior to the others, which was 54.06, 43.98, and 3.88 mg·kg^{-1}, in comparison to T_1, which was 25.44, 27.31, and 0.95. Although, there is a proportionate increase concentrations in the shoot system of *Dodonaea* with the increase of the addition levels but it did not go above allowed limits that were prepared by (FAO) and (WHO), which were 60 and 67.90 mg·kg^{-1} of dry matter for both zinc and nickel respectively. So when show Cd in shoot of *Dodonaea* with (FAO) and World Health Organization (WHO), we find that these parameters go above allowed limits that were 0.30. Hence, results are in agreement with what was stated by Azita and Seid, 2008 i.e. the increase of heavy metals in soil comes with an increase in the ability to the absorption of plants.

The contamination of plants criterions

Bioconcentration factor

Cadmium BCF2-Cd. Figure 4 shows the bioconcentration factor (BCF2) for cadmium in root system of the *Dodonaea* for the treatments. The results indicated high values of the bioconcentration factor for root of the *Dodonaea* plant and for all treatments, as the highest values of the bioconcentration factor for the element cd in root system of the *Dodonaea* plant in treatment T1 reached 1.74. All the values of the bioconcentration factor (BCF2) and all parameters of the *Dodonaea*, which is among the plants that have the ability to transport and accumulate cadmium in the root system, and this is consistent with the findings of Khan et al., 2007 who showed that plants growing in contaminated soil have coefficients High bioconcentration, exceeding the value of one according to this standard, and the highest value of the biotransfer factor (BCF2) for the shoot of lettuce plants growing in contaminated soil was for cadmium and nickel, greater than for lead. Shown in Figure 4 is the bioconcentration factor of the nickel element in root ofthe Didonia plant for the different treatments. If the results indicate that the bioconcentration factor of root ofall the treatments of the *Dodonaea* exceeded one, this indicates the ability of these plants to accumulate the element nickel in their root system. The BCF2 values for the *Dodonaea* plant ranged between 0.31–0.90.

Nickel element BCF2-Ni. Root ofwhite radish and carrot plants can be considered among the good accumulations of heavy elements, and that the nickel element has the ability to move and move from the soil to the shoot, and this was confirmed by Herati et al., 2011 who explained that the nickel

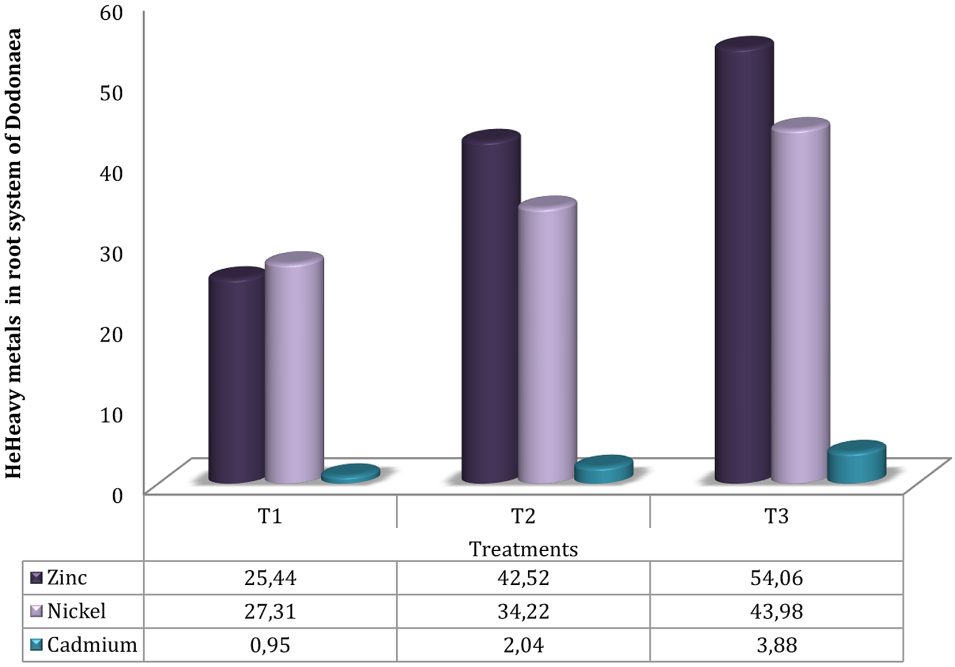


Figure 3. Total heavy metals concentration in shoot system of *Dodonaea* after experiment (mg·kg^{-1})

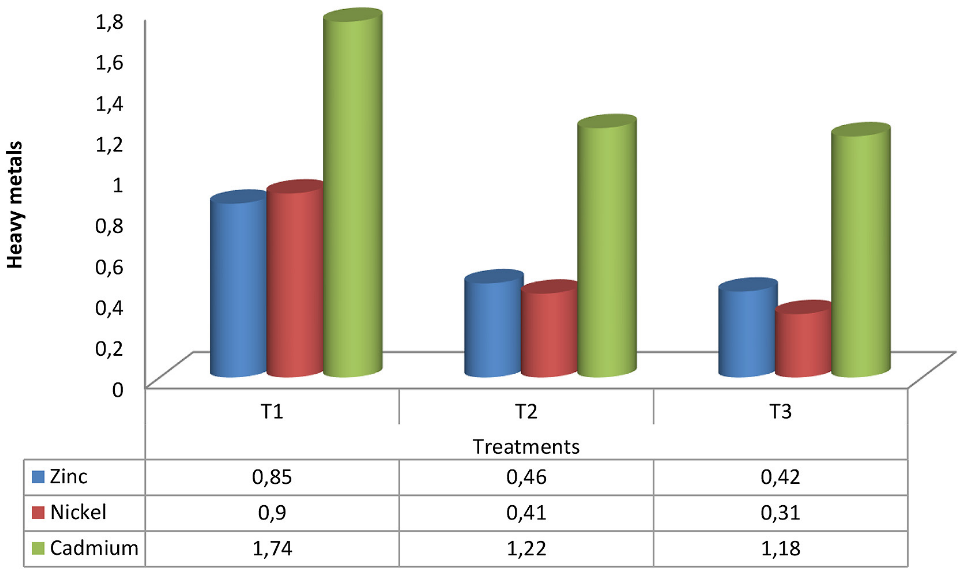


Figure 4. The bioconcentration factor in *Dodonaea* for zinc, nickel and cadmium

element is one of the mobile elements in the soil and the plant, as it is absorbed from the soil by the roots. Then it moves to the shoots and its accumulation in these parts increases with increasing levels of its concentrations added to the growth medium.

Zinc element BCF2-Zn. Figure 4 shows the bio-concentration factor of zinc in root ofthe *Dodonaea* plant for the different treatments. The results indicate high values of the bio-concentration factor BCF2 for the *Dodonaea* plant. The values ranged from 0.42 to 0.85, and all values did not exceed the value of one, and this indicates the ability of zinc to transfer and accumulate in the system. Root and vegetative roots of the *Dodonaea* plant. Zinc is one of the fast-moving elements in the soil and inside the plant because it is a nutrient that the plant needs during its growth stages. This is consistent with the findings of Subhashini and Swamy (2014) who explained that the zinc element has a high ability to move and move within the soil and the plant, and that increasing its system and then transported and collected in the shoot.

Hence, *Dodonaea* is one of the most important accumulators, for cadmium accumulation in it;

these results are in agreement with what was stated by Ammar and Nasr, 2017 who state that *Dodonaea* is the best tree in its accumulation of heavy metals.

Bioaccumulation coefficient

BAC stands for bioaccumulation coefficient, which measures the ratio of heavy metal concentrations in plant shoots to those in soil. According to the data in Figure 5, the BAC values for Dodonaea span from 0.45 to 0.95 for Zinc, 0.33 to 0.96 for nickel, and 0.77 to 0.85 for cadmium. This indicates that *Dodonaea* exhibits a moderate capability for bio accumulating Zinc and Nickel. This finding aligns with Malayeri *et al.* (2008) who assert from 0.1 to 1 are considered to have a moderate bioaccumulation capacity.

Translocation factor

Cadmium element TF-Cd

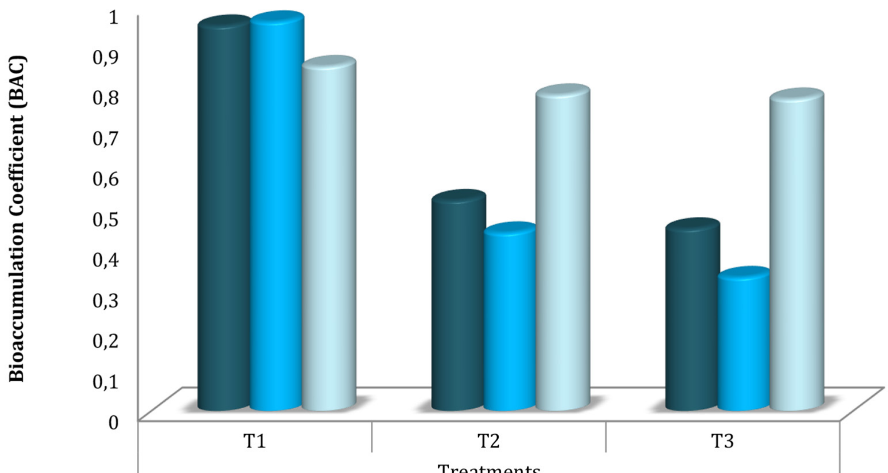
Figure 6 shows the site transfer factor of the element cadmium in the cadmium plant for the different treatments. The results indicated an increase in the site transfer factor of the plant. The highest values were in treatment T3, which was 0.66 compared to the measurement treatment T1, which was 0.49. It is noted from the previously mentioned results that for all treatments there were high values. The local transfer factor for cadmium, TF-Cd, is less than the value of one. According to this factor, the results indicate the presence of movement and transport of this element within the plant, as the cadmium element moved from the root system towards the shoot. This is consistent with what was stated by Abdel-Baqi (2000) and Al-Otaibi (2007)

Nickel element TF-Ni

Figure 6 shows TF for nickel in the Didonia plant for the different treatments. TF for the plants ranged between 1.05–1.09. It is noted from the above-mentioned results that the location transfer coefficient for the nickel element and for all coefficients exceeded the value of one, and this indicates the presence of movement and transfer of this element within the plant, as the element moved from the root system towards the shoot, and this is consistent with the findings of Mazin, 1995 who mentioned that the nickel element It is one of the mobile elements inside the plant, as it moves from the root system to the upper parts of the plant, and its accumulation increases in the upper parts compared to the root system with increasing levels of it added to the soil and according to the treatments used. As Khan et al. (2007) mentioned, the nickel element is one of the mobile elements inside the plant, as it moves from From the root system to the shoot, the accumulation of nickel in plants increases with increasing levels in contaminated soil.

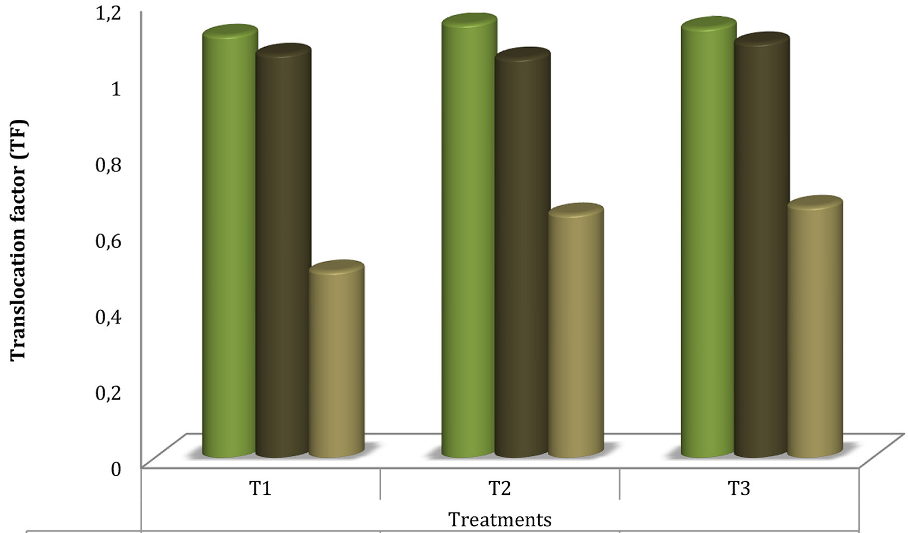
Zinc element TF-Zn

Figure 6 shows the site transfer factor of zinc in the Didonia plant for the different treatments. The results showed high values of the site transfer



	T1	T2	T3
Zinc	0,95	0,52	0,45
Nickel	0,96	0,44	0,33
Cadmium	0,85	0,78	0,77

Figure 5. The bioconcentration factor in *Dodonaea* for zinc, nickel and cadmium



	T1	T2	T3
Zinc	1,11	1,14	1,13
Nickel	1,06	1,05	1,09
Cadmium	0,49	0,64	0,66

Figure 6. Translocation factor for zinc, nickel and cadmium in *Dodonaea*

factor (TF-Zn) for the plant, and the values ranged from 1.11–1.14. The aforementioned results showed that the values of the local transmission coefficient for all treatments exceeded the value of one, and this indicates a high local transmission coefficient. We conclude that this element has the ability to move and move from the root system to the upper parts of the plant. This is consistent with what was stated by Selvaraj et al. (2013) and Ardalan et al. (2014) and Subhashini and Swamy (2014) who explained that plants have a high ability to accumulate and accumulate zinc within their tissues. Zinc is characterized by its rapid movement within the plant because it is one of the micronutrients. Which leads to its movement and transfer from the root system to the vegetative system within the plant and its increase in its accumulation in other parts. So, these heavy metals have been increased in soil as illustrated in Figure 7.

CONCLUSIONS

In the light of the previous analysis, the study has come up with the following conclusions: *Dodonaea* plant is a good bioaccumulator of the heavy elements Cd, Ni, and Zn in its various tissues, and it can be used in the process of bioreclamation of areas contaminated with these elements. Also Increasing the concentrations of zinc, nickel and cadmium in

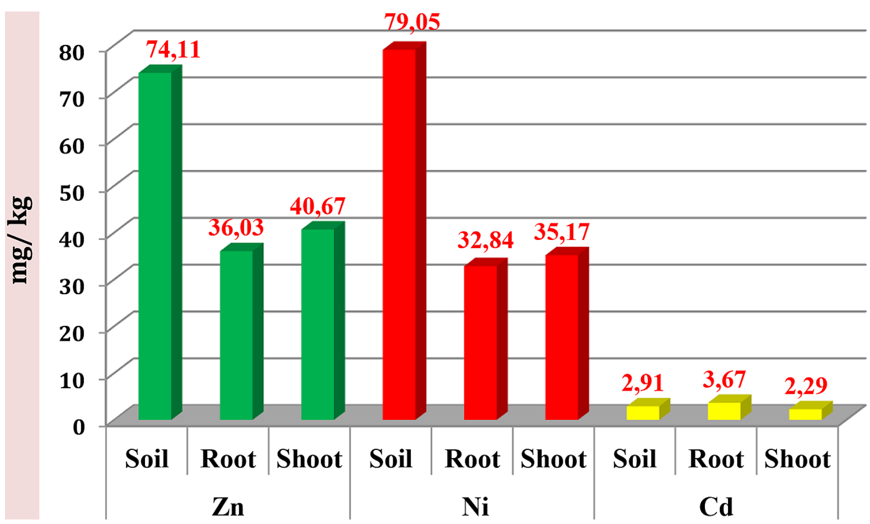


Figure 7. Average values of metals in the study soil and parts of the *Dodonaea* plant

soil (in root-shoot systems) of *Dodonaea* that was go along with the increase of the additional Zn, Ni and Cd of soil under study. BCF values of cadmium were surpassed 1, which refers to that *Dodonaea* has the ability to phytoextration of Cd in root system.BCF values of zinc and nickel did not go above 1, indicating that *Dodonaea* is one of the plants that has moderate bioaccumulation properties based on heavy metals. BAC values did not go above 1, which means that *Dodonaea* is moderately bio-accumulating for the heavy metals (cadmium, nickel and zinc). This research sets a new precedent for future studies, as it underscores the originality and effectiveness of our novel phytoremediation method using *Dodonaea* in the T3 treatment group, offering a groundbreaking solution to the challenge of industrial soil contamination.

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