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Electro Phytoremediation with Innovative Methods in Soils Contaminated with Heavy Metals

Abstract: - The reduction of the ecosystem's ability to renew itself due to human intervention has led to pollution of the air and water, as well as contamination of soil resources. Additionally, heavy metals present in soils are recognized as primary hazardous pollutants capable of exhibiting toxicity and carcinogenic effects due to their high density. The presence of these pollutants in the environment has always caused negative effects on the health of humans, plants, and animals.

Since the cleaning of contaminated soils using chemical and physical methods requires high economic costs, techniques considered as cheap alternatives are used instead. These techniques are phytoremediation, electro-phytoremediation, and electrokinetic methods, which involve the use of plants for the remediation of contaminated soils and have begun to be used for the removal of heavy metals. In this study, a total of 12 pots with different working conditions were set up with soils contaminated with Pb, Cd, Cr, Cu, and B elements: control 1 (phytoremediation), control 2 (electro-phytoremediation), control 3 (electrokinetic), and control 4 (sample specimens). For this purpose, canola plants were studied in soils with added Pb, Cd, Cr, Cu, and B elements using a periodic application of 30 V voltage and 4 hours of continuous DC current for 30 days. The use of graphite electrodes showed better removal of heavy metals. In the phytoremediation system with electrical stimulation, a moderate increase in pH was observed. The maximum amounts of lead and copper were obtained from the above-ground parts of the plants under electrical stimulation conditions, while the maximum amounts of chromium, cadmium, and boron were obtained from the roots. According to the results, plants stimulated by electrical current grew better and absorbed more metals. Based on the obtained results, the amounts of elements absorbed by the plants per kilogram of dry weight were determined using an ICP device. The results indicate that the electro-phytoremediation technique appears promising for the remediation of soils contaminated with heavy metals.

Keywords: Phytoremediation; Electro-phytoremediation; Contaminated Soil; Canola.

I. INTRODUCTION

With the increasing advancements in technology, soil contamination has emerged as a significant environmental issue globally. Soil pollutants originate from agricultural areas (pesticides and commercial fertilizers), mining sites, untreated energy facilities (thermal and nuclear power plants), industrial areas (paper, cement, textiles, etc.), and the surroundings of road transportation areas.

Soil pollution can be defined as the degradation of the physical, chemical, and biological properties of soils due to substances added from external sources or improper agricultural practices, apart from those originating from soil formation (Ertan KARA 2018).

Pollutants causing soil contamination can be classified as organic and inorganic pollutants. Heavy metals are among the primary inorganic pollutants. The most significant organic pollutants are persistent organic pollutants. The major source of heavy metal pollution comes from solid waste. The primary pollutants found in solid waste are chromium, along with small amounts of copper, boron, lead, and zinc. Heavy metals, which form a dangerous group of pollutants, can lead to adverse neurological and hormonal effects on humans. Additionally, they can cause allergic reactions, genetic mutations, and the death of beneficial bacteria in the body (Siegel, 2020).

Pollution originating in agricultural regions poses a serious threat to human health. Increased cadmium levels in plants and water due to reasons such as the use of phosphate fertilizers and irrigation of agricultural fields with wastewater can lead to health problems such as connective tissue cancer, chronic diseases, and diarrhea when the threshold values are exceeded (Özaslan, 2006).

The elements studied, Cd, Cr, Cu, Pb, and B, are commonly found in Turkish soils. For instance, lead can be found in regions with heavy traffic on highways, cadmium often originates from phosphate fertilizers used in agricultural areas, and boron is abundant in Turkish soils. Therefore, within the scope of this thesis, the uptake capacities of these elements by canola, one of the most widely cultivated plants in Turkey, have been investigated. In this study, phytoremediation and electrokinetic methods were investigated for the remediation of soils contaminated with Pb, Cd, Cr, Cu, and B elements. For this purpose, soils contaminated with Pb, Cd, Cr, Cu, and B elements were treated using canola plants to

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examine phytoremediation processes. In the experimental studies, after adding $Pb(NO_3)_2$, $CdCl_2$, K_2CrO_7, $CuSO_4$, and H_3BO_3 to the soil, canola seeds were planted, and their growth was observed with necessary irrigations at suitable intervals.

In this study, the determination of the elements absorbed by the roots and aboveground organs of plants, each plant was individually harvested from the pots, dissolved, and their soluble components were analyzed using an ICP device to determine the element contents. Based on the results obtained, the amounts of elements absorbed per kilogram of dry weight of the plants were determined.

II. MATERIALS AND METHODS

In this study, using the canola plant belonging to the Cruciferae family, the elements lead, cadmium, copper, chromium, and boron, which are commonly found in Turkish soils, were investigated under pot and open-air conditions. Details of the experimental methods, including information on the elements used, plants, and other materials, are provided below.

Materials

In this study, the uptake performances of the canola plant for different elements (Pb, Cr, Cu, Cd, B) have been compared.

Elements

The lead, cadmium, chromium, copper, and boron elements used in the experiment were obtained in the form of Pb(NO3)2, CdCl2, K2CrO7, CuSO4, and H3BO3. These compounds were added to the soil in solid form after necessary calculations.

Plants

In phytoremediation studies, canola plants were used. The seeds of these plants were obtained from a specialized seed company. The variety used was "Orkan," which is a medium-early variety of canola.

Soil Preparation

First, soil samples were taken from the Environmental Engineering Faculty's land at depths of 0-30 cm, and their coordinates were recorded at the site. The soil samples were then transferred to the laboratory and left to air-dry under normal conditions.

The soil samples were sieved through sieves with mesh sizes of 0.5 mm, 1 mm, and 2 mm, and 100 mg portions from each were prepared for analysis. After sieving, they were dried in an ashing furnace at 105 degrees Celsius for 6 hours, and the moisture content of the soil was calculated. The samples were then removed from the dryer and weighed.

In the experiments, the soil used was screened to remove stones and other coarse materials, passing through 4 mm sieves, and then left to dry (Figure 2.1). Subsequently, 3 kg of soil per pot was prepared by weighing it on sensitive scales to ensure accuracy.

Figure 2.1. Soil Drying and Preparation

Based on the information gathered from the literature and considering the toxicities of elements to plants, the soil was amended with 43 mg B/kg, 250 mg Pb/kg, 400 mg Cd/kg, 226 mg Cr/kg, and 185 mg Cu/kg.

The weighted compounds calculated according to the above table were thoroughly mixed into each pot until homogenized.

Soil Physical and Chemical Properties

For the physical and chemical analysis of the soil, samples taken from 0-30 cm depth were analyzed in the materials laboratory of Gebze Technical University according to standard methods, as reported in Table 2.2, which outlines some of the soil's physical and chemical properties.

Table 2.1. Soil analysis results.

	Dirty Soil
pH (1:1)	8,00±0,01
sand (0,02-2 mm) (%)	84,6±2,3
Plate (0,002-0,02 mm) (%)	8,4±0,5
clay (<0,002 mm) (%)	7,0±0,6
Texture class	CL (Killi tın)
Kireç ($CaCO_3$) (%)	7,26±0,41
organic matter (%)	5,27±0,24
Organic C (%)*	1,41

The total metal analysis of the soil was performed according to the EPA 3051A method using a microwave, and the concentrations of metals were determined with an Agilent 7500 CE model ICP-MS device.

Figure 2.2. Images of devices used in the research

Planting and Care

In the scope of the study, 12 pots have been selected. Each pot is filled with 3 kg of soil and contaminated with heavy metals. Accordingly, 12 seeds are scattered in each pot. Thus, 12 seeds are sown in each pot as canola. Three pots have been selected as control pots. A ruler was placed in each pot to observe the growth process. Among the many sprouted plants in each pot, well-sprouted ones are selected, and thinning is done to leave two plants in the middle of the pot. Over time, it has been observed that the canola plant is affected by the concentration of the boron element added to the soil and starts to wilt. Therefore, the boron dose has been reduced to 0.430 grams, and experiments with the boron element have been repeated.

In addition to the study, electrodes have been placed in three large transparent pots, with 6 graphite electrodes measuring 13cm in length and 4cm in width each. Seeds have also been planted in these pots in the same way. During this process, after the seeds have sprouted for 10 days, 30V of electricity has been applied every 4 hours. The growth of the plants is being observed.

Figure 2.3. germination and growth of Plants

Within the scope of the study, the growth of the plants is being monitored, and regular care is being provided. After the three-month period elapses, harvest procedures will be carried out, followed by further analyses to evaluate the results.

Harvest

Plant samples have been cut with steel scissors 2 cm above the soil surface. The roots have been separated from the leaves and stems, and all samples have been washed with deionized water and left to dry.

Figure 2.4. growth of plants

Method

Electro-Phytoremediation

Soil remediation with Electro-Phytoremediation involves applying low-intensity direct current between electrodes placed in the soil to mobilize the charged species as pollutants. Ions and small charged particles are transported between the electrodes with water. Anions move towards the positive electrode, while cations move towards the negative electrode. The applied current causes the charged species, particles, and ions in the soil to move through processes such as electromigration (transport of charged chemical species under an electric gradient), electroosmosis (transport of pore water under an electric gradient), electrophoresis (transport of charged particles under an electric gradient), and electrolysis (chemical reactions related to the electric field).

You've highlighted the method's primary advantage, which is its potential as a low-cost process for both in-situ soil remediation and post-excavation soil treatment. However, the necessity of having a conductive pore liquid within the soil mass imposes limitations dependent on the land's characteristics. Additionally, the presence of significant metal objects, rocks, formations, debris, and other obstacles in the contaminated area can reduce the efficiency of the remediation process (Acar and Gale, 2014).

Phytoremediation tests were conducted in pots containing 3 kg of dry soil with a moisture content of 41% (saturated soil). In tests involving electrical currents, a constant potential gradient of 1V/cm was applied using graphite electrodes directly inserted into the soil samples within the reactor. The electrode spacing was 10 cm. The graphite electrodes were plates measuring 13 cm in length and 4 cm in width. The study examined the effects of alternating current (AC) and direct current (DC) applied for 4 hours. The DC-P tests used periodically applied direct current: 4 hours of the same periodic application of DC current. (30V and current between 2 and 3).

The electric field was applied only from the 10th day of plant growth to allow seedlings to germinate and develop before the application of the electric current. The study will focus on germination rate, plant growth, biomass production, and the removal of contaminants (heavy metals).

In this research, the cultivation of canola and sunflower plants in soil contaminated with Cd, Pb, Cu, B, and Cr is expected in three different pots (electric current, normal, and electric current with plants) trials. As part of the experimental studies, after adding $Pb(NO_3)_2$, $CdCl_2$, $CuSO_4$, K_2CrO_4, and H_3BO_3 to the soil, canola seeds are planted, watered at appropriate intervals, and their growth is observed. A decrease in growth is expected in plants grown in soils contaminated with heavy metals as a result of changes in physiological and biochemical processes.

Contaminated soil electrokinetic remediation occurs by applying low-intensity current between electrodes placed in the soil. This process involves moving pollutant charges through the application of a weak electric current between electrodes inserted into the soil. The movement of charged ions in the soil due to the applied current is investigated through electromigration, electroosmosis, and electrolysis methods.

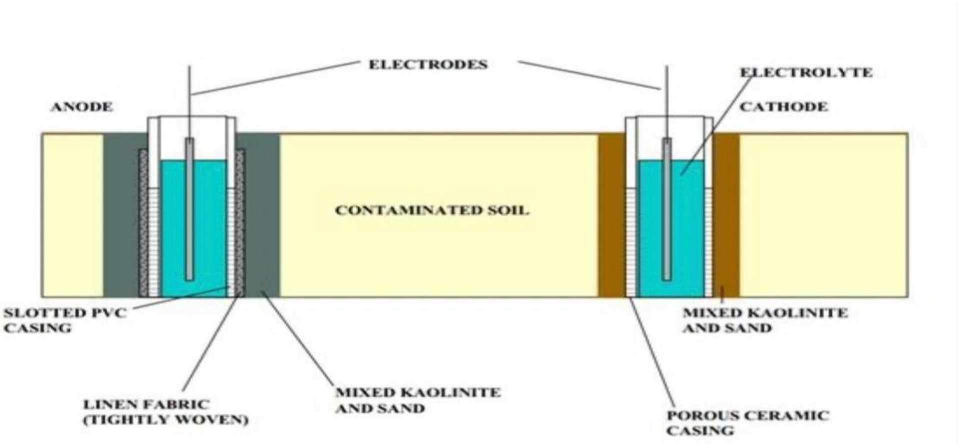


Figure 2.5. Removal scheme of heavy metals in the soil environment by electric current method

The application of Electro-Phytoremediation technologies is highly effective for the removal of pollutants in fine-textured and highly permeable soils. The direction and extent of movement of the pollutant between the electrodes are determined by various factors, including the type, concentration of the pollutant, soil structure, and surface chemistry.One of the significant advantages of electro-phytoremediation technologies is that they offer an economical process for both in-situ soil remediation and post-excision soil treatment (ex situ).

Electro-Phytoremediation experiment (on plants)

Phytoremediation tests were conducted in pots containing 300 grams of dry soil with a moisture content of 41% (saturated soil). In tests involving electrical currents, a constant potential gradient of 1V/cm was applied using graphite electrodes directly inserted into the soil samples within the reactor. The electrode spacing was 10 cm. The graphite electrodes were plates measuring 10 cm in length and 4 cm in width. The study examined the effects of continuously applying alternating current (AC) and direct current (DC). The DC-P tests involved periodically applying direct current with 4 hours of continuous usage.

Experimental studies have been conducted in pots both in a controlled environment and under open-air conditions using soils to which synthetic elements have been added. Pots containing 3 kg of soil with added lead, chromium, copper, cadmium, and boron elements have had canola (rapeseed) seeds planted. The plants are being watered at regular intervals and receiving necessary care. Rulers have been placed in the pots, and the growth of plants is being measured daily. The plants will be harvested at three-month intervals for analysis.

Analysis of soil and plant parts

The soil samples were air-dried in an oven at 75°C until reaching a constant weight over two days. Subsequently, the samples taken from the oven were stored in a desiccator until the time of analysis. Then, 2 grams of soil samples were weighed on a sensitive balance. The weighed samples were placed in 250 ml beakers, covered with watch glasses, and positioned on a water bath at 95°C on a hot plate.

In the process using the soil analysis method (EPA 3050 B), a 10 ml solution consisting of 5 ml distilled water and 5 ml HNO3 was added to the sample in a beaker. The mixture was heated in a water bath for 15 minutes and then allowed to cool. After placing the samples back in the water bath, 5 ml concentrated HNO_3 was added in three repetitions at 15-minute intervals until solid particles dissolved. Subsequently, a 5 ml solution composed of 2 ml water and 3 ml H2O2 was added to the sample..

3 ml of H2O2, totaling up to 10 ml, was added at 15-minute intervals until foaming ceased completely. After 15 minutes, once more, 10 ml of distilled water and then 5 ml of HCl were added to the dissolved samples in the beaker. The beakers were then taken out of the water bath and allowed to cool after the additions..

The cooled samples were filtered through Whatman 41 filter paper in a 100 ml volumetric flask. The same procedures were carried out for the control sample, mirroring the steps taken for the samples with added metals and completing the soil digestion process.

Figure 2.6. Preparation of plant materials for analysis

Chemical analysis

The solutions obtained after dissolution were analyzed for the elemental contents using AAS (Atomic Absorption Spectroscopy) and ICP (Inductively Coupled Plasma) devices. Standards of 1 ppm, 2 ppm, 5 ppm, and 10 ppm were prepared for the calibration of Cr, Cd, Pb, Cu, and B analyses. Both standards and plant samples were analyzed using the ICP device.

Calculation of Soil and Plant Element Amounts

The analysis results from the devices allowed for the calculation of the amounts of extracted elements separately for the soil and for the roots and above-ground parts of the plants.

Calculation of Element Concentrations in Plants

For calculating the amounts of elements in the plants, separate analyses of the roots and above-ground parts of the plants were conducted.

III.RESULTS

Element Uptake Performance of Canola Plant (Electro Phytoremediation)

When examining the Cr element in canola plants, it was found that in the first repetition (T1), there was an accumulation of 65.45% in the leaves+flowers part. In the second repetition (T2) and the third repetition (T3), the accumulation in the root section was 67.89% and 65.52%, respectively. Additionally, the table below provides the above-ground chromium values:

Table 3.1. Canola Plant's Cr Element Uptake (Electricity Flow).

Canola Plant's Cr Element Uptake (Electricity Flow)								
	Root		Trunk		Leaf+Flower		Whole Plant	above ground
Repeat	Mg/kg	%	Mg/kg	%	Mg/kg	%	Mg/kg	Mg/kg
T1	25,46	84,7%	7,84	26,08%	6,84	18,45%	39,74	2,35
T2	20,76	67,89%	4,39	14,36%	5,427	17,75%	20,58	1,58
T3	17,85	65,52%	5,16	18,94%	4,234	15,54%	24,25	0,87

When looking at the graph for the Cr element in canola plants, it is observed that heavy metals are being extracted more from the plant with the support of electric current compared to other methods.

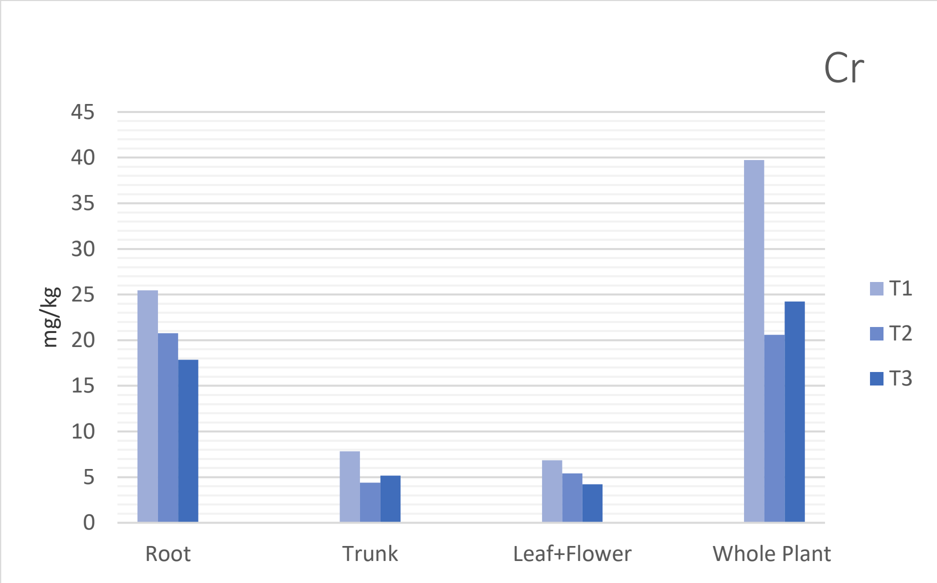


Figure 3.1. Cr Element Uptake of Canola Plant (Electricity Flow)

When examining the Cd element in canola plants, in the first repetition (T1), there was an accumulation of 45.99% in the leaves+flowers part. In the second repetition (T2), the accumulation was in the root (36.90%) and stem (35.78%) parts. In the third repetition (T3), there was an accumulation of 52.36% in the root part. Additionally, the table below provides the above-ground cadmium values.

Table 3.2. Cd Element Uptake of Canola Plant (Electricity Flow)

Cd Element Uptake of Canola Plant (Electricity Flow)								
	Root		Trunk		Leaf+Flower		Whole Plant	above ground
Repeat	Mg/kg	%	Mg/kg	%	Mg/kg	%	Mg/kg	Mg/kg
T1	88,23	25,53%	98,44	28,48%	158,95	45,99%	345,69	9,96
T2	141,64	36,90%	176,13	35,78%	134,53	27,33%	452,3	3,71
T3	91,67	52,36%	41,72	23,83%	41,69	23,81%	175,05	8,98

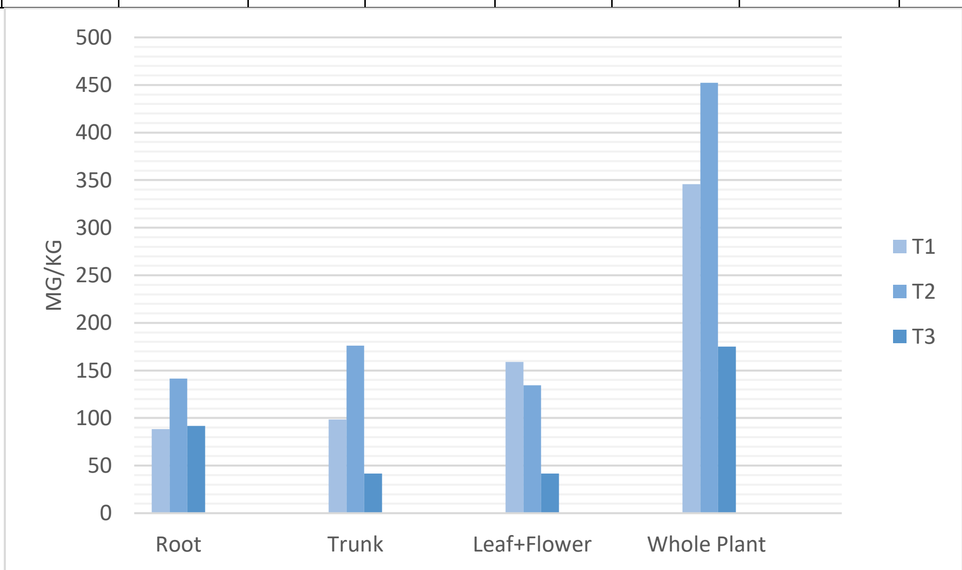


Figure 3.2. Cd Element Uptake of Canola Plant (Electricity Flow)

When examining the Pb element in canola plants, in the first repetition (T1), there was an accumulation of 53.92% in the root part. In the second repetition (T2) and the third repetition (T3), the accumulation was in the stem part with rates of 46.66% and 64.51% respectively.

Table 3.3. Pb Element Uptake of Canola Plant (Electricity Flow)

Pb Element Uptake of Canola Plant (Electricity Flow)								
	Root		Trunk		Leaf+Flower		Whole Plant	above ground
Repeat	Mg/kg	%	Mg/kg	%	Mg/kg	%	Mg/kg	Mg/kg
T1	58,82	53,92%	27,32	23,05%	22,94	21,03%	109,08	1,23
T2	53,33	25,65%	34,2	24,66%	57,56	37,69%	145,89	2,54
T3	38,57	25,47%	32,36	24,51%	41,23	23,01%	112,16	3,06

As observed in the graph, it has been determined that the lead element is being extracted from the plant as a result of the electric current.

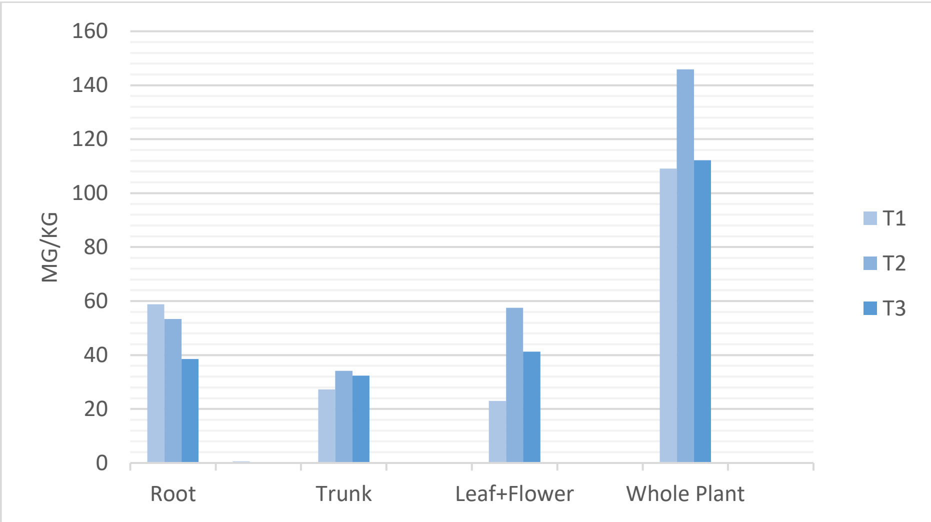


Figure 3.3. Uptake of Pb Element by Canola Plant (Electricity Flow)

When examining the Cu element in canola plants, it was observed that the accumulation was in the root part in all three repetitions. In the first repetition (T1), the accumulation was 64.97% in the root, in the second repetition (T2) it was 57.02%, and in the third repetition (T3) it was 47.23%.

chart 3.4. Canola Plant's Cu Element Uptake (Electricity Flow)

Canola Plant's Cu Element Uptake (Electricity Flow)								
	Root		Trunk		Leaf+Flower		Whole Plant	above ground
Repeat	Mg/kg	%	Mg/kg	%	Mg/kg	%	Mg/kg	Mg/kg
T1	340,68	64,97%	175,7	27,29%	82,2	25,74%	598,7	3,28
T2	267,69	57,02%	158,36	24,61%	73,35	18,37%	499,25	2,63
T3	161,71	47,23%	197,28	28,41%	83,43	24,36%	542,29	1,54

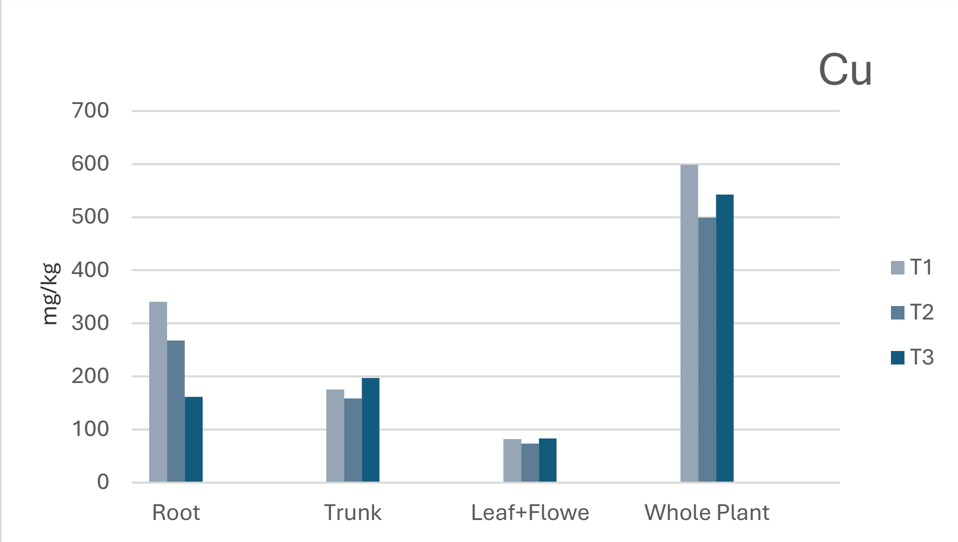


Figure 3.4. Cu Element Uptake of Canola Plant (Electricity Flow)

When examining the B element in canola plants, it was observed that the accumulation was in the leaves+flowers part in all three repetitions. In the first repetition (T1), the accumulation was 45.10% in the leaves+flowers part, in the second repetition (T2) it was 23.16%, and in the third repetition (T3) it was 42.45%.

Table 3.5. B Element Uptake of Canola Plant (Electricity Flow)

Element B uptake (electricity flow) of the canola plant								
	Root		Trunk		Leaf+Flower		Whole Plant	above ground
Repeat	Mg/kg	%	Mg/kg	%	Mg/kg	%	Mg/kg	Mg/kg
T1	51,69	21,28%	53,25	21,62%	78,3	45,10%	183,31	6,35
T2	58,82	23,16%	35,25	19,68%	80,1	48,16%	174,7	7,65
T3	43,16	17,79%	59,62	23,76%	69,4	42,45%	172,94	3,72

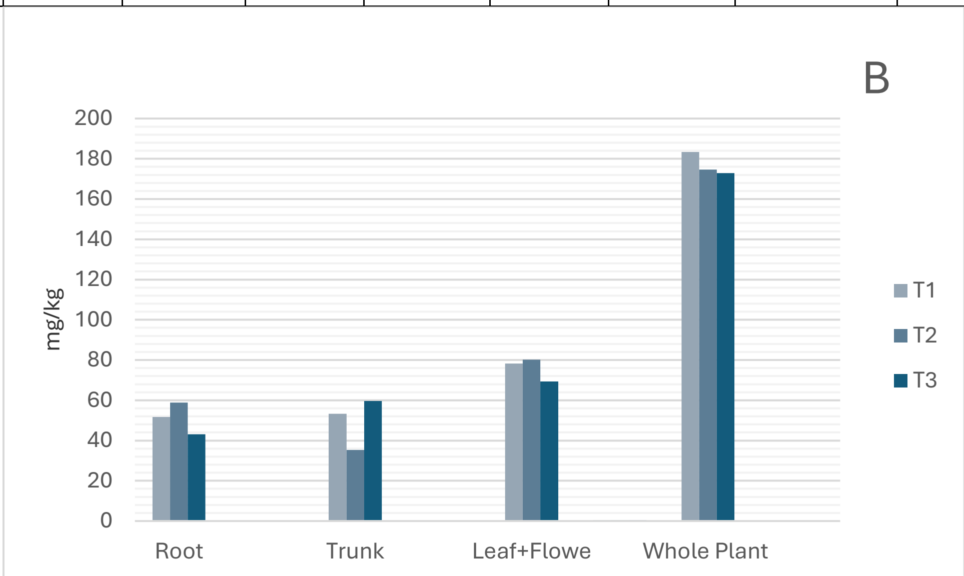


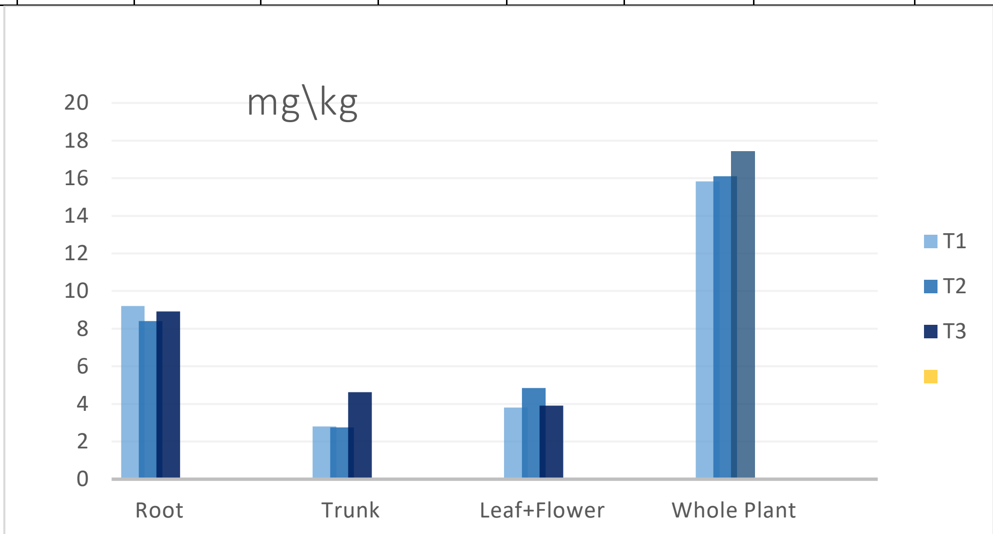
Figure 3.5. B Element Uptake of Canola Plant (Electricity Flow)

Element Uptake Performance of Canola Plant (Phytoremediation).

When examining the Cr element in canola plants, it was observed that in the first repetition (T1), there was an accumulation of 28.18% in the root part. In the second repetition (T2) and the third repetition (T3), the accumulation remained in the root part with rates of 22.53% and 21.09%, respectively. Additionally, the table below provides the above-ground chromium values.

Table 3.6. Cr Element Uptake of Canola (Rape) Plant

Cr Element Uptake of Canola (Rape) Plant								
	Root		Trunk		Leaf+Flower		Whole Plant	above ground
Repeat	Mg/kg	%	Mg/kg	%	Mg/kg	%	Mg/kg	Mg/kg
T1	9,21	28,18%	2,81	17,76%	3,80	18,05%	15,83	3,25
T2	8,41	22,53%	2,75	17,18%	4,85	19,97%	16,1	2,56
T3	8,91	21,09%	4,62	19,49%	3,91	18,42%	17,44	1,24



Shape 3.6. Cr Element Uptake of Canola Plant

When the Cd element in canola plants was examined, it was observed that in the first repetition (T1), there was an accumulation of 19.21% in the root part. In the second repetition (T2), the accumulation was in the stem part with a percentage of 25.60% and in the third repetition (T3) with a percentage of 21.53%. Additionally, the table below provides the above-ground cadmium values.

Table 3.7. Cd Element Intake of Canola (Rape) Plant

Cd Element Intake of Canola (Rape) Plant								
	Root		Trunk		Leaf+Flower		Whole Plant	above ground
Repeat	Mg/kg	%	Mg/kg	%	Mg/kg	%	Mg/kg	Mg/kg
T1	29,6	19,21%	22,35	19,38%	89,50	25,40%	141,45	3,25
T2	28,5	18,70%	42,31	25,60%	75,85	24,70%	146,66	2,14
T3	18,9	16,85%	34,41	21,53%	31,22	20,62%	84,53	4,23

As seen in the graph of cadmium element in canola plant, the highest accumulation is observed in the second repetition (T2) throughout the entire plant.

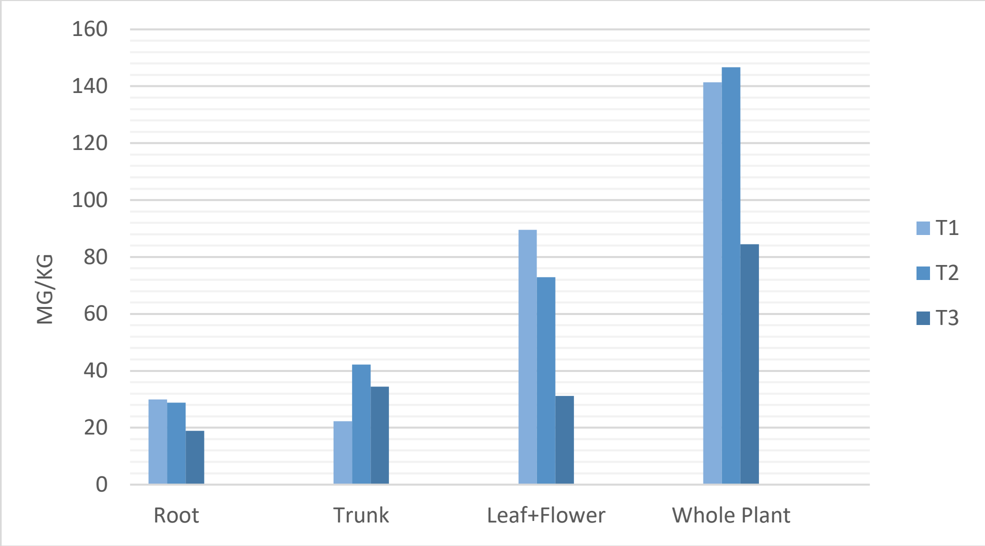


Figure 3.7. Cd Element Uptake of Canola Plant

When examining the Pb element in canola plants, it was observed that in the first repetition (T1), there was an accumulation of 26.28% in the root part. In the second (T2) and the third repetition (T3), the accumulation was in the leaves+flowers part with percentages of 18.59% and 19.31%, respectively.

Table 3.8. Pb Element Uptake of Canola (Rape) Plant

Pb Element Uptake of Canola (Rape) Plant								
	Root		Trunk		Leaf+Flower		Whole Plant	above ground
Repeat	Mg/kg	%	Mg/kg	%	Mg/kg	%	Mg/kg	Mg/kg
T1	31,76	26,28%	17,24	18,49%	16,41	17,23%	65,41	2,65
T2	28,05	17,34%	26,26	21,08%	27,33	18,59%	81,64	3,25
T3	28,09	18,48%	25,33	20,20%	27,92	19,31%	81,34	3,26

As seen in the graph, it has been observed that heavy metals are withdrawn from the plant..

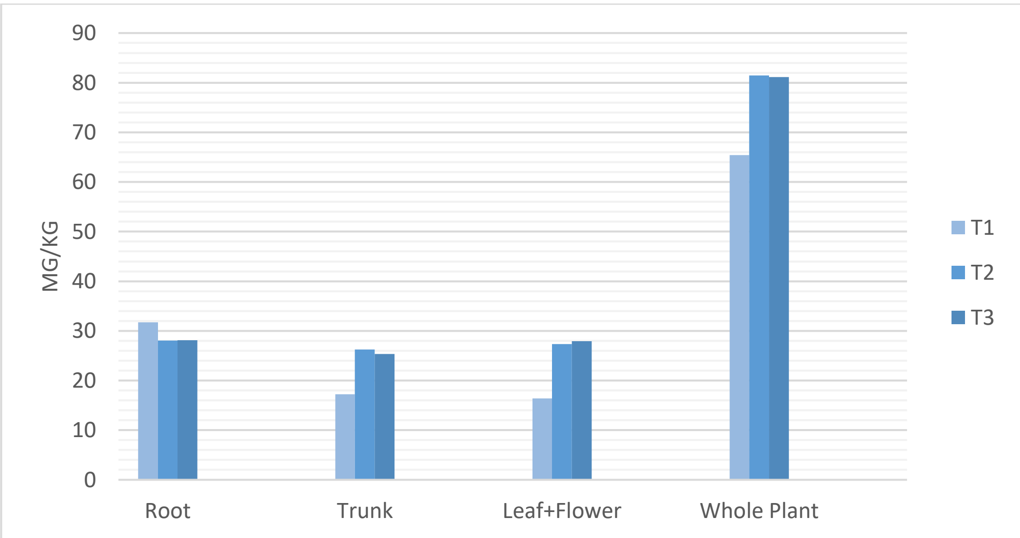


Figure 3.8. Pb Element Uptake of Canola Plant

When examining the Cu element in canola plants, it was found that there was an accumulation in the root part in all three repetitions. Specifically, in the first repetition (T1), there was an accumulation of 53.26% in the root part, in the second repetition (T2) it was 50.28%, and in the third repetition (T3) it was 54.76%.

Table 3.9. Cu Element Uptake of Canola (Rape) Plant

Cu element uptake of canola (rapeseed) plant								
	Root		Trunk		Leaf+Flower		Whole Plant	above ground
Repeat	Mg/kg	%	Mg/kg	%	Mg/kg	%	Mg/kg	Mg/kg
T1	201,8	53,26%	116,8	30,83%	60,275	15,91%	378,87	2,31
T2	159,8	50,28%	95,71	30,12%	62,3	19,60%	317,81	3,25
T3	221,8	54,76%	112,89	27,87%	70,33	17,36%	405,02	2,12

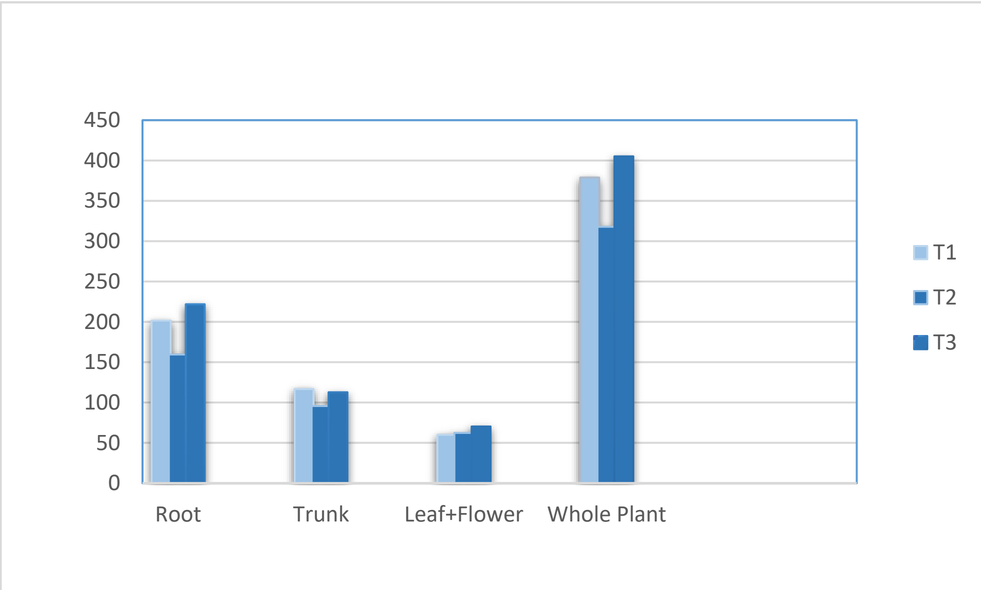


Figure 3.9. Cu Element Uptake of Canola Plant

When examining the B element in canola plants, it was found that there was an accumulation in the leaves+flowers part in all three repetitions. Specifically, in the first repetition (T1), there was an accumulation of 41.66% in the leaves+flowers part, in the second repetition (T2) it was 41.24%, and in the third repetition (T3) it was 45.80%.

Table 3.10. B Element Intake of Canola (Rape) Plant

B Element Intake of Canola (Rape) Plant								
	Root		Trunk		Leaf+Flower		Whole Plant	above ground
Repeat	Mg/kg	%	Mg/kg	%	Mg/kg	%	Mg/kg	Mg/kg
T1	40,87	29,31%	40,48	29,03%	58,09	41,66%	139,44	1,56
T2	35,89	23,91%	52,33	34,86%	61,91	41,24%	150,13	2,35
T3	25,19	23,30%	33,41	30,90%	49,51	45,80%	211,24	2,28

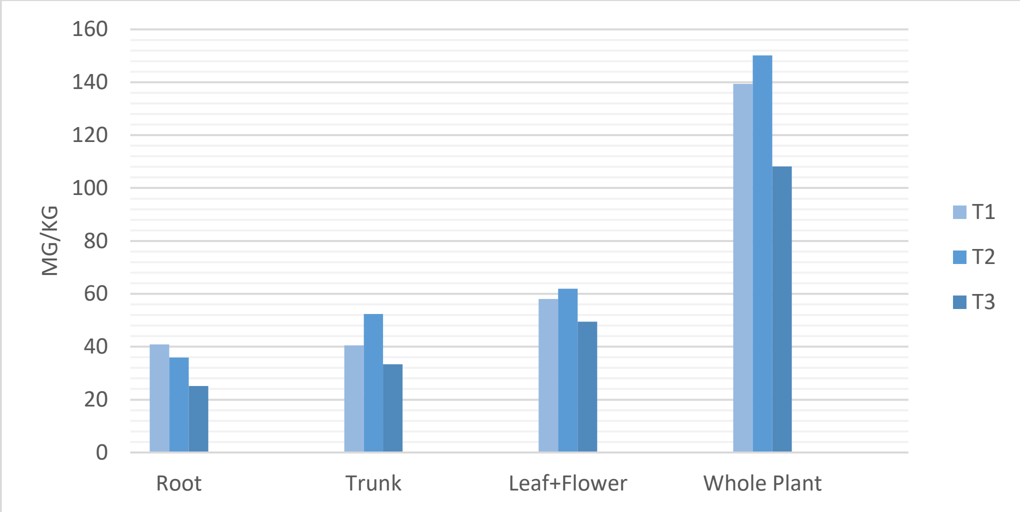


Figure 3.10. B Element Intake of Canola Plant

IV.CONCLUSION

Baker theory suggests that canola plants successfully transport elements they uptake to their above-ground parts, making them efficient accumulators. When the uptake times of elements from soils by canola plants were examined, it was noted that these times were long for all elements except boron. This is an expected outcome for electrophytoremediation. However, the required times for cadmium, copper, boron, and lead were deemed exceptionally long.In the experiments, the plants were harvested after a 10-week growth period to maintain the experimental conditions, minimize plant losses, and facilitate calculations, rather than waiting for the normal vegetation period of 14-15 weeks. This shorter period is considered brief for plant species with normal durations of 14-15 weeks. Allowing the full durations would result in a higher accumulation of elements. Electrophytoremediation as a remediation technology requires more than merely high pollutant uptake performances from plants; factors such as physical, chemical, physiological, and meteorological elements also influence its efficiency and applicability. Soil structure and pH are crucial factors for plant growth. Additionally, the final disposal options of plants used for electrophytoremediation affect suitable plant selection. For instance, when selecting plants that may be used in animal feed, preference should be given to plants that accumulate pollutants in their roots rather than in their leaves. Therefore, proper plant selection for electrophytoremediation and phytoremediation applications considers all these factors.

The aim of accumulating elements from soils using plants is to transform the elements retained in the soil into a more controllable and transportable form. Therefore, electrophytoremediation and phytoremediation methods should not be considered as final disposal methods. Final disposal or removal can involve incinerating the plants arising from electrophytoremediation and phytoremediation, or storing them in a suitable storage area.

In conclusion, the field of electrophytoremediation and phytoremediation presents a new and ecological opportunity with significant potential. In the advanced stages of phytoremediation, it will require an interdisciplinary approach that combines botany, genetic biotechnology, soil chemistry, microbiology, agriculture, and environmental science.

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