The Effect of Magnetized Water on the Absorption of Cadmium Using Synthetic Effluents by Lantana *camara* Species

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Abstract

Background: Magnetization of water, as a factor that stimulates the other factors related to plant growth, is an affective physical solution on plant resistance and yield.

Methods: In this case-control research, the effect of magnetized water on cadmium removal by *Lantana camara* was investigated. An experiment with completely randomized-block design was done to irrigate the plant pots using 3 levels of water treatment (W1: magnetic, W2: semi-magnetized and W3 non-magnetized:) and 4 levels of cadmium 0, 0.5, 1, and 2 mg/L with 3 replications.

Results: The results showed that the interaction effects of cadmium levels and irrigation water treatment on soil, shoot, and root cadmium content were significant. The amount of soil cadmium decreased by 39.49 percent by increasing the concentration of metal (2 mg/L) in irrigation water under the influence of magnetized water treatment. Evaluation of cadmium accumulation, adsorption index and transfer factor showed that the highest amount of them in the treatment of 2 mg / l cadmium in the surface of magnetized water was equal to 0.836, 0.034, and 1.654 respectively. The lowest shoot and root cadmium under the influence of magnetic water treatment was 0.559 and 0.303 (mg Kg^{-1}), respectively, which was significant compared to non-magnetized water treatment. The enzyme activity of CAT (Catalase), SOD (superoxide dismutase), POD (peroxidase), phenol, phenoloid, and anthocyanin was increased by applying magnetic water treatment.

Conclusion: Magnetized water by increasing the cadmium absorption by plants and stimulating the plant antioxidants had a significant effect on the absorption and transport of cadmium and increased the efficiency of refining plants by *Lantana camara* plant.

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Introduction

Water scarcity is one of the challenges that has affected most parts of the world. Therefore, researchers have turned their attention to the use of unconventional waters (saline and industrial and urban effluents) in recent years.[1] In general, irrigation with effluents can have several beneficial and harmful effects on the soil, plants, and soil biology.[2] One of the negative effects is the increase in the concentration of heavy metals in the soil and finally in the plant due to long-term use of municipal or industrial effluents.[3] The use of different recycled waters in irrigation can affect the chemical properties of the soil, by means of increasing the heavy metals and nutrients contents, and changing acidity and salinity. Physical properties (like permeability, stability of structure and hydraulic conductivity) and biological characteristics (such as microbial biomass and activity of various enzymes) can be affected as well. For reducing the adverse effects of using effluent in irrigation, appropriate strategies should always be applied to lead to sustain development of irrigation; phytoremediation process is a common way to reduce these adverse effects. During this process, plants cultivated in contaminated areas which have a high ability to uptake heavy metals; change the contaminations into less dangerous compounds and thus reduce their negative effects, through absorption of soil and water contaminants in the plant structure.[4] Species from high biomass and resistance to heavy metal toxicity such as *Lantana Camara* (*Lantana camara* shrub) are usually used in this remediation process.[3] The family *Verbanaceae* includes 100 genera and more than 2000 species. The genus *Lantan* belongs to this family, which includes 150 plant species.[5]

Lantana camara, also known as wild sage, is a thorny multi-stemmed, deciduous shrub with an average height of 2m (6ft). The taxonomic position of the shrub is defined as belonging to the class of magnoliopsida, order lamiales, family verbenaceae and genus, Lantana.[6]

Stems are square in outline, covered with bristly hairs when green, and often armed or with scattered small prickles. *Lantana camara* possesses a strong root system. The roots even after repeated cuttings give new flush of shoots. Leaves are opposite, simple, with long petioles and oval blades which are rough and hairy and have blunt toothed margins. The leaves of Lantana camara have a strong aroma.[7] In a study, the absorption ability of Co, nickel, cadmium, and lead from wastewater using *Lantana camara* was surveyed; the results showed that *Lantana camara* species were significantly effective in removal of heavy metals from the environment. Based on results of another study, *Vetiver* and *Lantana camara* species showed the high potential of wastewater treatment.[8, 9] Although phytoremediation technology is eco-friendly and affordable, but for some reasons such as time consuming, it may be less attractive to refine.[10] That is why the use of upgrading technologies in this field can be very important. One of these improvement methods is the use of irrigation water magnetization technology.[11] During the magnetization, water is exposed to a magnetic field and changes the water properties including optics, electromagnetism, thermodynamics, and mechanics (dielectric constant, viscosity, surface tension force, freezing and boiling points and electric conductivity).Thus, magnetized water has extensive applications in industry, agriculture, and medicine.[12]

Magnetic water improves the plant growth by causing chemical changes in the plant growth structure, thus acting as a stimulant of plant growth-related factors.[13] Magnetized water is obtained by passing a stream of water through a magnetic field and changing a number of its physical and chemical properties.[14] Numerous studies have been conducted on the issue of phytoremediation.[15-18] In addition, there have been numerous reports of increasing the immune function of magnetically treated plants; for instance, in a research it was shown that Cadmium contaminated soil can be treated by phytostabilization using *Vetiver*.[19] In another study entitled *Magnetic treatment of irrigation water: Its effects on vegetable crop yield and water productivity,* the results indicated some beneficial of magnetized water for irrigation water on the yield and water productivity of celery and snow pea plants.[20] Magnetic treatment of irrigation water has proved to influence the precipitation of salts, concentration of ions, pH, and electrical conductivity.[21, 22] The effect of magnetic field on physical and chemical properties of water and on the activity of corn antioxidant system showed that the magnetic field increased the plant resistance environmental damage. In description of this phytoremediation mechanism, it can be mentioned that plant resistance is increased by the activity of catalase, polyphenol oxidase, peroxidase, and superoxide dismutase enzymes.[23] The stimulating effects of magnetic water on increasing the plant growth (plant height, leaf area, and number of leaves, stomata, dry and wet weight of roots) and performance may be related to the absorption and availability of elements for absorption. Research has also shown that irrigation with magnetic water may be considered as an effective method to improve the growth and water content of the plant.[24, 25]

Given the importance of environmental protection, contamination reduction, and using environmental friendly methods, and because the sewage effluent is a source of cadmium entry into the soil, this research was conducted to investigate the effect of magnetic field on the absorption of cadmium in synthetic effluent by *Lantana camara* plant.

Methods

Geographical Location of the Research Site

This study was conducted in the central nursery of Green Area and Parks Organization Bandar Abbas Municipality (Latitude: 27° 21' and Longitude: 56° 35' N), Bandar Abbas, Iran (Figure 1), from March 20, 2020 to February 18, 2021.

Materials

In order to study the effect of magnetic field on cadmium (Cd) uptake by *Lantana Camara*, we conducted a pot experiment in plastic pots with

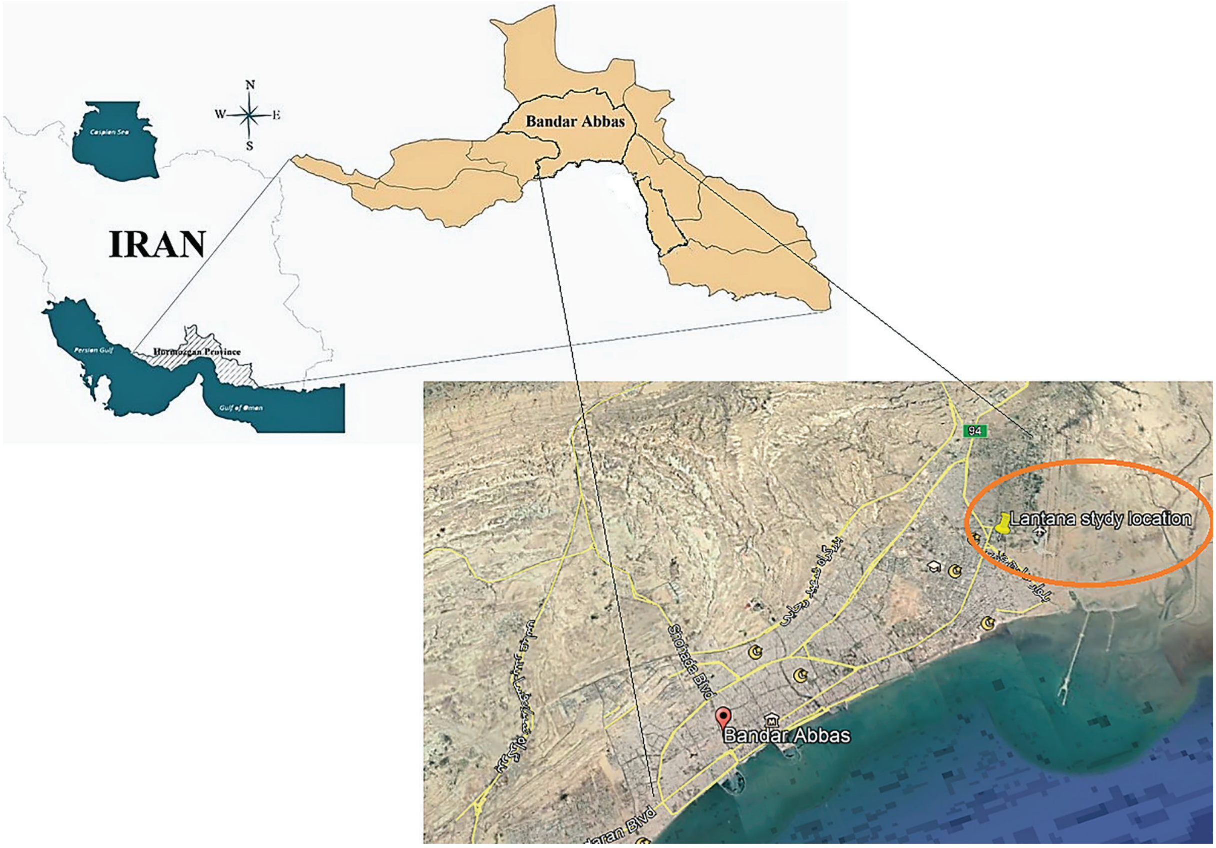

Figure 1: Location of the study. The map is extraction using google Earth.

a height of 60 cm and mouth opening diameter of 42cm as a factorial arrangement based on a completely randomized design with three replications. The studied soil was sampled (surface layer, 0-30 cm) from an agricultural soil located in Baghu village, Bandar Abbas, Iran; after air-drying, it was sieved (2 mm) to determine some physical [soil texture[26]] and chemical properties [pH,[26] Electrical Conductivity (EC),[27] Organic Carbon (% OC),[28] Calcite %,[26] N,[29] P,[30] and available form of Fe, Mn, Pb, and Cd.[31]

All pots were filled with 10 kg of soil. The studied treatments were Cd in 4 values (0, 0.5, 1 and 2 mg. l^{-1}) and irrigation water in 3 levels (magnetized water, semi-magnetized water, and non-magnetized water). The Cd levels were added to the irrigation water as the cadmium nitrate. In the semi-magnetized water treatment, irrigation with magnetized water and non-magnetized water was done twice a week, so that once non-magnetized water was used, and once magnetized water was used.

Lantana plant, from species of *Lantana Camara*, with a height of 20 cm was obtained from the greenhouse of Bandar Abbas municipality. To prevent the possibility of root damage, we irrigated the plants with distilled water for one month until they were fully established. Based on the results of soil analysis, the nutrients requirements were added to the pots as fertigation. The soil moisture was held near the field capacity (FC) by weighting the pots and replacing the lost water. The duration of the pot experiment was 5 months.

Magnetizing the Irrigation Water

In this experiment, in order to magnetize the water, we used a magnetic water generating device (prepared from Fapan Company) called a magnetic ion stirrer with an intensity of 110 Tesla. The device consists of a non-magnetic tube (steel) on which a number of magnets are placed in a ring on it in such a way that it produces a dense and variable (i.e., sinusoidal) magnetized water (Figure 2).

The amount of consumed water was determined according to the water needs of the plant. In order to water magnetize the plant, we passed different effluent treatments with various cadmium concentrations through a magnetic device.

The Soil and Plant Measurements

Towards the end of experiment, the homogeneous soil sample which we took from each pot for 7 days was oven-dried at 70° for 72 hours. Finally, we measured the concentration of available Cd.[20]

We rinsed the samples taken from the above-mentioned ground and root of the plant using water and then 3 times using distilled water. Once transferred to laboratory, the samples were dried for a duration of 48 hours at 60c and weighed at the end. Then, by the use

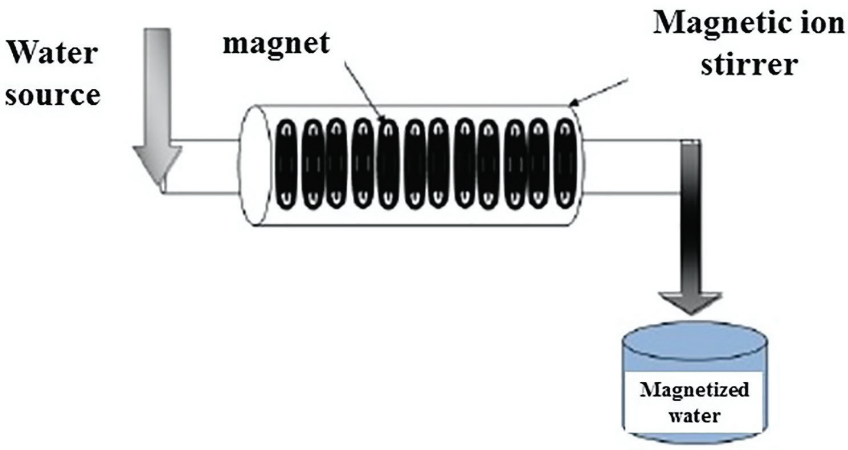

Figure 2: The magnetic ion stirrer and method of production of magnetized water

of dry asking method, we measured Cd concentration in the roots and shoots of the mentioned sample.[32]

The shoots and roots were first washed thoroughly in deionized water to remove the soil particles and then in 1 mM H-EDTA (pH 5.0) at 4°C for 30 min. They were oven-dried at 70°C for 48h and weighed. Subsamples (1 g) of the dried plant tissue were digested in a mixture of HNO3/HClO4 (1:1.5), and the lead concentration was determined by atomic absorption spectrophotometry, AAS (Varian Spectra AA220, Lab Recyclers, USA).[33]

Activity of the Plant Enzymes

To measure some of the index enzymes of the antioxidant system and non-enzymatic antioxidants, we washed fresh leaf samples with distilled water to fix the biochemical measurements in liquid nitrogen; then, they were maintained in freezer at -80°C. In this step, the activity of Superoxide Dismutase,[34] Catalase and Peroxidase,[35] total Flavonoids, Phenol,[36] and total Anthocyanin[37] was measured.

Superoxide Dismutase (SOD) Enzyme Activity

To determine the Superoxide dismutase (SOD) enzyme activity, we isolated 200mg from the frozen culture cells in 3 ml HEPES-KOH buffer with pH 7.8 containing 0.1 mM EDTA.[34] The resulting homogenate was centrifuged at 12,000g/min for 15 minutes at 4°C; then, the floating part was used to measure the superoxide dismutase activity. Reaction composition in the final volume of 3ml including HEPRS-KOH buffer, 5 mM with 7.8: pH containing 0.1 mM EDTA, Na2CO3, 50 mM with 10: 2: PH, L-methionine 12 mM, NBT Tetrazolium Blue Nitro 75 µM, riboflavin 1 µM, and enzyme extract was selected in appropriate amounts. One unit of SOD activity was considered as the enzyme value, which resulted in a 50% inhibition of nitrobltetrazolium (NBT) at 560nm (Ghanati et al. 2005). The reaction mixture absorption rate was measured using a spectrophotometer (UV-Vis 1280).

Catalase Enzyme (CAT) Activity

Frozen samples were extracted at a rate of 100 mg in 3ml of 60 mM sodium phosphate buffer with pH=1.7. The resulting homogenate was centrifuged at 15,000 rpm for 15 minutes at 4°C. The supernatant was used to measure the activity of the peroxidase solution. The reaction of composition in the final volume of 3ml including 6mM Na-Phosphate buffer with pH=1.6, Gauiacol 28 mM, 5 mM H2O2 and enzyme extract was selected in appropriate amounts. Enzymatic activity was measured by increasing the adsorption at 470 nm / min per mg of protein in the enzyme extract using a spectrophotometer (UV-Vis 1280).[35]

Peroxidase (POX) Activity

To extract the dissolved peroxidase, 200 mg of the frozen cell mass was ground in 60 mM sodium phosphate buffer (pH 6.1) on ice and centrifuged (12000 rpm, for 30 minutes). The reaction of mixture consisted of 60 mM sodium phosphate buffer (pH 6.1), 28 mM guaiacol, and 5 mM hydrogen peroxide and enzymatic extract. The absorbance of the samples was measured during one minute at a wavelength of 470 nm using a spectrophotometer (UV-Vis 1280).[35]

Total Flavonoid Activity

To measure flavonoids, 200 mg of frozen cell mass was thoroughly ground in 3 ml of acidic ethanol (ethanol and acetic acid in a ratio of 99: 1) and centrifuged (12000 rpm for 15 minutes). After being filtered, the supernatant was placed in a warm water bath at 80°C for 10 minutes. The absorption rate of the samples after cooling was read by spectrophotometer (UV-Vis 1280) at three wavelengths of 270, 300, and 330 nm. The quenching coefficient of 33000 Cm-1M−1 was used to calculate the concentration of flavonoids.[36]

Total Anthocyanin Activity

In order to measure the total anthocyanin activity, we thoroughly ground 200mg of frozen cell mass in 3ml of acidic methanol (including methanol and hydrochloric acid in a ratio of 99 to 1); then, the resulting extract (12000 rpm, for 15 minutes) was centrifuged. After being filtered, the supernatant was placed in the dark overnight and then absorbed at 550 nm with a spectrophotometer (Cintra6, GBC, Victoria, Australia). The extinction coefficient of 33000 Cm−1M-1 was used to calculate the concentration of anthocyanins.[37]

Total Phenol Activity

To extract phenol, we ground 200 mg of frozen cell mass in 3 ml of methanol and after homogenization of the extract (12000 rpm, centrifuged for 8 minutes). Then, 0.5 ml of Folin-ciecalteu reagent was added to 0.5 ml of topical solution; 1 ml of 20% Na2CO3 was added after 5 minutes and then rested at room temperature for 10 minutes. The total amount of phenolic compounds was calculated by measuring the absorbance of the samples at a wavelength of 730 nm spectrophotometer (model), using the standard gallic acid curve.[36]

The Pollution Indices

Translocation factor (TF) was calculated from the ratio of the metal concentration in the leaf to the metal concentration in the root, and bioaccumulation factor (BF) was obtained from the ratio of the metal concentration in the root to the total concentration of the metal in the soil. Also, the index of total Cd uptake of biomass (UI) was calculated by multiplying the concentration of Cd in different parts of the plant by the dry weight of the biomass.[38]

Statistical Analysis

Statistical analysis of the data was done using SAS 9.1 software, the means were compared according to Duncan's multiple-range test (DMRT) ($P<0.05$), and the graphs were drawn using Excel software.[39]

Results

Analysis of Soil and Wastewater

Table 1 presents the results of physico-chemical parameters of the soil used before applying the experimental treatments. The results showed that the soil content did not contain cadmium and its texture was sandy-loamy.

Physical and chemical properties of wastewater effluent are determined in Table 2. As shown in the Table, the content of wastewater effluent does not contain cadmium and the concentration of other heavy elements can be used for irrigation of green space.

Cd Concentration in the Soil and Plant Tissues

The type of water used in irrigation treatment is effective in fluctuations of the soil cadmium concentration, so that the lowest concentration of cadmium content in the soil was observed in the application of magnetized water under zero cadmium treatment (Table 3).

The concentration of cadmium in the roots and shoots also increased significantly when the Cadmium content increased due to contaminated irrigation water (Table 4).

Translocation Factor, Uptake Index, Bioaccumulation Factor

As shown in Table 5, the interaction of irrigation water and cadmium concentration on uptake index and bioaccumulation factor was significant. The amount of uptake index in the magnetized water treatment increased significantly compared to other irrigation treatments. The results related to the bioaccumulation factor were the same as the uptake index.

Table 1: Physical and chemical parameters of the soil

EC (dS/m)	pH		Soil bulk density (g/cm3)		SP%		%OC	Soil texture
1.9	7.55		12		34		1.18	Sandy loam
%Sand	**%Silt**	**%Clay**	**Mn (mg/kg)**	**Cd (mg/kg)**	**Fe (mg/kg)**	**K (mg/kg)**	**P (mg/kg)**	**N (%)**
78	2	10	6.1	0	4.3	30	6.5	0.08

Table 2: Physical and chemical properties of wastewater

PH	(opacity NTU)	EC (dS/m)	TSS (mg/L)	BOD_5 (mg/L)	COD (mg/L)	P (mg/L)	Fe (mg/L)
7.5	40.7	4.3	63.2	34.36	84.7	3.36	0.07
$(No_3)^{-2}$ (mg/L)	**K (mg/L)**	**Cu (mg/L)**	**Mn (mg/L)**	**Zn (mg/L)**	**Cd (mg/L)**	**Pb (mg/L)**	
4.4	14	0.01	0.11	0.054	0	0	

Table 3: Interaction effects of the studied treatments on the soil Cd in Lantana camera plant

Magnetized water	Cd concentration (mg L^{-1})			
	Soil Cd (mg Kg^{-1})			
	0	0.5	1	2
W1	00.0±0.0^{dA}	0.18±0.00^{cC}	0.30±0.00^{bC}	0.50±0.0^{aC}
W2	00.0±0.0^{dA}	0.30±0.00^{cB}	0.41±0.00^{bB}	0.58±0.00^{aB}
W3	00.0±0.0^{dA}	0.42±0.02^{cA}	0.56±0.01^{bA}	0.83±0.02^{aA}

Cd: Cadmium

Table 4: Interaction effects of the studied treatments on the Root Cd and Shoot Cd in Lantana camera plant

Magnetized water	Cd concentration (mg L^{-1})							
	Root Cd (mg Kg^{-1})				Shoot Cd (mg Kg^{-1})			
	0	0.5	1	2	0	0.5	1	2
W1	00.0±0.0^{cA}	0.218±0.035^{bA}	0.269±0.016^{aA}	0.303±0.003^{aA}	00.0±0.0^{dA}	0.282±0.019^{cA}	0.4710±0.003^{bA}	0.559±0.016^{aA}
W2	00.0±0.0^{cA}	0.180±0.012^{bB}	0.264±0.006^{aA}	0.282±0.007^{aA}	00.0±0.0^{dA}	0.207±0.006^{cB}	0.321±0.036^{bB}	0.441±0.016^{aB}
W3	00.0±0.0^{cA}	0.163±0.007^{bB}	0.192±0.004^{bB}	0.230±0.010^{aB}	00.0±0.0^{cA}	0.197±0.003^{bB}	0.227±0.009^{bC}	0.354±0.018^{aC}

Data presented are the mean±SE. For each column (lowercase letters at each Cd concentration) and row (capital letter at each irrigation water treatment) for root or shoot dry weight, significant differences at P<0.05 have been indicated with different letters. Cd: Cadmium

Table 5: Interaction effects of the studied treatments on UI, BF in lantana camera plant

Magnetized water	Cd concentration (mg L^{-1})							
	UI				BF			
	0	0.5	1	2	0	0.5	1	2
W1	0^{cA}	0.020^{bA}	0.033^{aA}	0.034^{aA}	0^{dA}	0.500^{cA}	0.740^{bA}	0.836^{aA}
W2	0^{dA}	0.017^{cAB}	0.026^{bB}	0.033^{aA}	0^{dA}	0.387^{cB}	0.586^{bB}	0.723^{aB}
W3	0^{cA}	0.015^{bB}	0.018^{bC}	0.028^{aB}	0^{cA}	0.360^{bB}	0.419^{bC}	0.583^{aC}

Data presented are the mean±SE. For each column (lowercase letters at each Cd concentration) and row (capital letter at each irrigation water treatment) for the root or shoot dry weight, significant differences at P<0.05 have been indicated with different letters. Bf: Bioaccumulation factor; UI: uptake Index

Irrigation type treatments and different levels of cadmium were significantly high on transfer factor (TF) (Table 6a-6b). With increasing cadmium concentration compared to the controls, the transfer factor increased significantly at all cadmium levels (6a).

Dry Biomass Yield of the Roots and Shoots

Root dry weight values are displayed in Table 7. According to the results, the highest root dry weight in all levels of cadmium was observed in the complete magnetic water treatment, which was notably different from other irrigation treatments.

Based on the results of Table 8-a, increasing the cadmium concentration led to a decrease in the shoot dry weight. Also, with the change of irrigation type from magnetized to non-magnetized state, the dry weight decreased, but this reduction was not significant (8-b).

Biochemical Properties

The levels of Catalase and Peroxidase enzyme activity are shown in Table 9. According to these results, the activity of catalase and peroxidase by increasing cadmium concentration compared to the control treatment showed an important growth under the influence of magnetized water.

The type of irrigation and the concentration of cadmium on the activity of SOD enzyme are presented in Table 10-a, b. The results showed that

Table 6a: Amount of TF as affected by magnetized water in Lantana camera

Cd concentration (mg L-1)	TF
0	0.00±0.00^{c}
0.5	1.237±0.06^{b}
1	1.395±0.032^{b}
2	1.654±0.067^{b}

Data presented are the mean±SE, significant differences at P<0.05 have been indicated with different letters. Cd: Cadmium; TF: Translocation factor

Table 6b: Amount of TF as affected by different Cd in Lantana camera

Magnetized water	TF
W1	1.239±0.033a
W2	0.987±0.083b
W3	0.988±0.081b

Data presented are the mean±SE, significant differences at P<0.05 have been indicated with different letters.

by changing the type of irrigation from magnetized to semi-magnetic and non-magnetic state, SOD activity was remarkably reduced. On the other hand, with increasing the concentration of cadmium, the amount of this enzyme showned an increase in all levels of irrigation.

Table 10-a, b shows the level of anthocyanin activity under the influence of irrigation type and cadmium content. According to Table 10-a, by raising the level of cadmium concentration, anthocyanin activity level was raised significantly. The highest level of anthocyanin activity was measured in

Table 7: Interaction effects of the studied treatments on the root dry weight in lantana camera plant

Magnetized water	Cd concentration (mg L^{-1})			
	Root dry weight (g pot^{-1})			
	0	0.5	1	2
W1	3.6±0.35^{aB}	2±0.00^{bB}	2.7±0.40^{bB}	2.8±0.46^{abB}
W2	2.4±0.23^{bC}	2.3±0.17^{bB}	3.3±0.17^{aB}	2.2±0.12^{bB}
W3	4.6±0.35	4.2±0.12^{bcA}	5.4±0.23^{aA}	3.7±0.40^{cA}

Data presented are the mean±SE. For each column (lowercase letters at each Cd concentration) and row (capital letter at each irrigation water treatment) for root or shoot dry weight, significant differences at P<0.05 have been indicated with different letters.

Table 8a: Amount of TF as affected by magnetized water in Lantana camera

Cd concentration (mg L-1)	Shoot dry weight
0	47.4±1.73^{a}
0.5	42.1±0.76^{b}
1	38.6±2.02^{b}
2	38.9±1.63^{b}

Data presented are the mean±SE, significant differences at P<0.05 have been indicated with different letters. TF: Translocation factor

Table 8b: Amount of TF as affected by different Cd in Lantana camera

Magnetized water	Shoot dry weight
W1	41.2±2.04^{a}
W2	41.9±1.41^{a}
W3	42.2±1.68^{a}

Data presented are the mean±SE, significant differences at P<0.05 have been indicated with different letters. Cd: Cadmium; TF: Translocation factor

magnetic water treatment, which was statistically very high with the control sample.

The interactions of irrigation water on the activity of phenol and flavonoids are presented in Table 10. The results show a notable increase in the phenol and flavonoid activity in all cadmium levels as W1> W2> W3. Also, by increasing the concentration of cadmium to 2 mg / l, the activity of phenol and flavonoid increased remarkably.

Discussion

Cd Concentration in the Soil and Plant Tissues

As the results of variance analysis showed (Table 11), the interaction effects of cadmium levels and irrigation water treatment on the soil, shoot cadmium content (P<0.01), and roots (P<0.05) were considerable.

The increase in the soil cadmium concentration was achieved by increasing cadmium in irrigation water (Table 3). By increasing cadmium content in the irrigation water, the concentration of cadmium in the roots and shoots increased significantly (Table 4). In other words, with the magnetization of water, the amount of soil cadmium significantly decreased due to the increased solubility of cadmium and increased absorption by the plant. The reason for this is that the magnetic field causes changes in some physical properties of water by affecting the type of molecular vibrations of water. In addition, the induced magnetic field in water exerts a strong force on the hydrogen bond and by overcoming the van der Waals force, the number of free molecules in water increases sharply, which in turn increases the solubility of water. These results are consistent with those of other studies.[40, 41]

According to Ghanati et al. (2007), Zea mays

Table 9: Activity of Phenol, Flavonoid, catalase, and Peroxidase as affected by different Cd and magnetized water in Lantana camera plant

Magnetized water	Biochemical properties (Antioxidant Enzyme)							
	Cd concentration (mg L^{-1})							
	Phenol (µg/gFW)				Flavonoid (µmol/g.dw)			
	0	0.5	1	2	0	0.5	1	2
W1	84.5±0.60^{bA}	87.6±0.39^{bA}	85.1±0.49 ^{ba}	111.4±0.81^{aA}	176.2±0.58 ^{aA}	174.6±0.66^{aA}	175.2±0.35^{aA}	179.1±0.25^{aA}
W2	70.1±0.68^{cB}	85.1±0.49^{bA}	81.9±0.10^{bA}	107.4±0.27^{aA}	139.8±0.66^{cB}	148.6±0.91^{bcB}	161±0.58^{aB}	155.5±0.18^{abB}
W3	63.9±0.25^{cB}	81.5±0.87^{bA}	71.3±0.75^{cB}	109±0.2^{aA}	131.8±0.41^{bB}	138.1±0.68^{bc}	131.8±0.47^{bc}	151±0.58^{aB}
Magnetized water	**Biochemical properties (Non Antioxidant Enzyme)**							
	Cd concentration (mg L^{-1})							
	Catalase (nmol/min/ml)				**POD (Δbs 470/mg protein)**			
	0	**0.5**	**1**	**2**	**0**	**0.5**	**1**	**2**
W1	0.105±0.00 ^{bA}	0.105±0.006^{bB}	0.113±0.00^{abB}	0.116±0.003^{aA}	118.5±0.91^{dA}	149.6±0.54^{cA}	201.2±0.75^{bA}	251.9±0.10^{aA}
W2	0.099±0.00^{bAB}	0.102±0.001^{bB}	0.105±0.002^{abB}	0.111±0.006^{aAB}	113±0.51^{cA}	131±0.58^{bB}	194.4±0.54^{aA}	189.7±0.60^{aB}
W3	0.093±0.0001^{Db}	0.948±0.004^{bA}	0.982±0.001^{aA}	0.106±0.003^{cB}	107±0.41^{dA}	127.5±0.33^{cB}	178.3±0.79^{bB}	191.40±0.81^{aB}

Data presented are the mean±SE. For each column (lowercase letters at each Cd concentration) and row (capital letter at each irrigation water treatment) for root or shoot dry weight, significant differences at P<0.05 have been indicated with different letters.

Table 10a: Activity of Anthocyanin and Superoxide as affected by different Cd in Lantana camera plant

Cd concentration (mg L-1)	Anthocyanin (µg/gFW)	Superoxide dismutase (unit/mg protein.min)
0	10.8±0.51^{b}	196.1±2.21^{c}
0.5	11.4±0.56 ^{b}	214.5±3.42^{b}
1	13.7±0.94 ^{a}	214.1±3.08^{b}
2	14.5±0.73^{a}	376±2.57^{a}

Cd: Cadmium

Table 10b: Activity of Anthocyanin and Superoxide dismutase by magnetized water in Lantana camera plant

Magnetized water	Anthocyanin (µg/gFW)	Superoxide dismutase (unit/mg protein.min)
W1	14.5±9.87^{a}	263.3±2.29^{a}
W2	12.6±0.9^{a}	250.8±1.89^{a}
W3	10.8±0.36^{b}	236.4±2.04^{a}

Data presented are the mean±SE, significant differences at P<0.05 have been indicated with different letters

Table 11: Analysis of variance for of the studied traits in Lantana Camera plant

Source of Variation	df	Soil Cd	Root Cd	Shoot Cd	Root dry weight	Shoot dry weight	UI	BF	TF
Magnetized water (A)	2	0.1299**	0.0083**	0.0548**	13.29**	3ns	0.00012ns	0.103**	0.254**
Cd concentration (B)	3	0.6423**	0.1337**	0.3343**	2.03**	150.8**	0.00168**	0.882**	4.859**
A×B	6	0.0172**	0.013*	0.0096**	0.79*	27.6ns	0.00003**	0.016**	0.061ns
Error	24	0.0004	0.0005	0.0011	0.24	23.8	0.00001	0.001	0.040
C.V (%)		5.7	12.4	13.2	15.1	11.7	13.2	8.6	18.7
Source of Variation	**df**	**SOD**	**POD**	**CAT**	**Anthocyanin**	**Flavonoid**	**Phenol**		
Magnetized water (A)	2	2170.5**	2871.2**	7234**	42.1**	4498.8**	346.8**		
Cd concentration (B)	3	6397.9**	19051.5**	2485**	28.6**	247**	2274.4**		
A×B	6	73ns	611.7**	2507**	3ns	131*	61.7*		
Error	24	70.7	52.4	0.2	4.9	37	24.2		
C.V (%)		3.4	4.4	2	17.5	3.9	5.7		

df: degree of freedom, **values of significant at P<0.01, * values of significant at P<0.05, ns values not significant P>0.05.

L. extracted more nutrients because magnetized water accelerated the biosynthesis of polyphenols in the plant, especially anthocyanin and flavonoids.[42] Although there have been few studies on the effect of magnetic fields on the plant metal uptake capability, there are a few studies that are important. According to Khan et al. (2020), the magnetic field can activate the membrane transporters, which can extract the heavy metal that is relatively mobile in substrates containing critical elements.[43] In this study, the significant accumulation of cadmium in the roots and shoots of Lantana camara plant can be a good confirmation of this possibility (Table 4). Comparison of the amount of cadmium in the roots and shoots of Lantana camara plant showed that the accumulation of cadmium in the shoots was higher than the roots. Since the higher absorption of cadmium in the shoot is greater than the root and the shoot is easier to remove from the environment, this method will be an environmentally friendly and cost-effective method.

Translocation Factor, Uptake Index, Bioaccumulation Factor

Evaluation of cadmium accumulation and uptake index in *Lantana camara* plant (Table 3) showed that the highest amount of these two factors was magnetized in the treatment of 2 mg/L cadmium in water. Cadmium transfer factor (Table 5) as affected by absorption of 0, 0.5, 1, and 2 mg/L cadmium was 0, 1.237, 1.395, and 1.654, respectively. Magnetic water increases the bioaccumulation, transfer factors, and uptake index in *Lantana camara* plant. In other words, it can be concluded that increasing the absorption of cadmium in irrigation water and changing the irrigation pattern to magnetized state lead to increasing cadmium absorption and increasing cadmium transfer from the root to the shoot. Due to the presence of a magnetic field, cadmium is directed to fewer sensitive tissues. In addition, magnetic fields provide the energy needed for cadmium to pass between branches and leaves and neutralize the ion transfer barriers.[44] The study results showed that cadmium concentration in two plant species, N. caerulescens and T. arvense, increased linearly with increasing magnetic field strength, which led to an increase in cadmium TF.[30] According to studies, magnetic fields can increase the ability of *Lactuca Sativa* to absorb water and nutrients by activating *Auxin activity*, increasing the ability of plant cell wall expansion and improving cell differentiation and organ polarity.[45] Changes in the content of the soil mineral ions can be caused by changes in magnetized water. There have been identified differences in ion concentrations in the soil irrigated with magnetized water compared to the controls.[46] The concentration of Cd in the soil was substantially reduced in irrigation treatments with magnetized water compared to semi-magnetized water compared to non-magnetized water, which may be attributed to their greater uptake by plant roots due to improved solubility and ability to uptake.

There are many reports of significant accumulation of heavy elements with magnetized treatment in different organs of plants.

Dry Biomass Yield of the Roots and Shoots

The results showed (Tables 3, 5) that increasing the cadmium content of irrigation water leads to an increase in its absorption by the plant, causes toxicity, and thus reduces the plant growth; this result was in line of De Sousa et al research.[47] The presence of large amounts of cadmium in the soil leads to reduced growth, performance, and root activity; in a survey by Mitra et al. (2018), this finding was emphasized.[48] One of the reasons for this decrease is the physical and chemical reactions between heavy metals and soil components that lead to changes in the soil properties and reduced soil fertility.[16,49] Heavy metals also reduce the plant photosynthesis due to their effect on reducing water and nutrient absorption, which affects the plant growth and performance.[30]

The operation of magnetizing water in the process of absorption of metals from aqueous and terrestrial environments has a dual effect on the plant; firstly, magnetized water improves the concentration of chlorophyll a and b and total chlorophyll in the plant.

Furthermore, it increases the leaf growth rate.[34] The effect of low frequency magnetic fields positively changes the growth cycle and weight of the plant organs of *Lepidium Apetalum*, *Artemisia Vulgaris*, *A. Jacutica* and *A. Dracunculus*. In addition, the positive effects of magnetic fields on the increase of various biomass plant species have been confirmed.[44] According to Punamiya et al. (2010), vetiver shoot and root dry weight decreased significantly as Pb levels increased.[50] There was a major reduction in morphological response, as well as increased Pb accumulation in the roots under Pb stress.[51]

The results of this study are in agreement with the findings of other reserachers who reported plant biomass decreased with increasing Cd stress. However, magnetized water increases the absorption of toxic metals and their accumulation in the plant structure, which leads to reduction in the plant growth.

Biochemical Properties

The activity of SOD, POD, CAT, phenol and flavonoids, and anthocyanin compared to semi-magnetic and non-magnetic water treatments increased under the influence of magnetic water (Tables 10, 11). It reflects the first step in increasing free radical production in Lantana camara plant cells by magnetized treatment. Antioxidants not only play an important role in the protection mechanism, but also help the plants grow and develop.[52] SOD and POD are two essential antioxidant protection enzymes that can protect the plants from the adverse effects of ROS created by various stress conditions.[53] Increased levels of some polyphenols, such as anthocyanin, flavonoids, and phenol from magnetized treatment, which protect photosynthetic membranes from peroxidation, should not be overlooked; this result is in line with that of Ghamadi (2020).[54] As a result of the magnetized treatment, some tests revealed an increase in the enzyme activity.[55] According to Dhawi (2014), an increase in the number of hydrogen bonds in molecules, as well as an increase in cell permeability and active energy in cell electrolyte solutions, can affect the enzymatic activity and other biochemical reactions occurring in plants under the influence of magnetized treatment, which affects physiological processes in them.[56]

As the concentration of lead increased, the activity of antioxidant and non-oxidative enzymes increased; also, the activity of enzymes became significant compared to lower levels of lead (Pb: 0 and a 0.5 mg/L).

Sayed (2014) found that the magnetized treatment had a beneficial impact on growth promoters,[57] whereas Davies (2004) argued that plant phytohormones were involved in every aspect of plant growth and development.[58] Furthermore, magnetic fields not only allow heavy metals to move through the barrier between the shoots and leaves, but also neutralize the normal biological electric field in plants, preventing ions from migrating (Luo et al., 2019).[44] Environmental stresses, such as heavy elements, lead to overproduction of ROS in plants. ROS inhibition mechanisms play an important role in protecting the plants from environmental stresses. Antioxidants such as ROS inhibitory enzymes (SOD, CAT, POD, phenol, flavonoids, and anthocyanin) are directly involved in the plant cell homeostasis.[45]

The results of this study, like other studies, showed that cadmium stress activated the plant antioxidant systems.[49, 59] It also claimed that SOD, CAT, and POD in response to cadmium stress played an important role in maintaining redox homeostasis.[60] CAT is one of the three types of antioxidant enzymes which is an axial enzyme involved in the over-detoxification of H_2O_2 in cadmium stress.[61] On the other hand, POD activity is strongly induced by cadmium in the roots, stems and leaves, which indicates the essential role of POD in the removal of ROS.[14] SOD also converts O_2 to H_2O_2 and catalyzes oxygen and plays an important role in the antioxidant defense system of the plants. Flavonoids are synthesized in the cytoplasm as well as the cytoplasmic surface of the endoplasmic reticulum and, with their antioxidant activity, protect the plant against biological and non-biological stresses. Increased activity of anthocyanins, flavonoids, and phenol under magnetic water treatment may indicate that the path of biosynthesis of phenolic compounds has been in the direction of homeostasis.[62]

Antioxidant enzymes detoxify ROS through a series of reactions that function together in a synergistic manner. However, it is important to note that one of the novel aspects of our research was the determination of magnetized water of enzymatic on nonenzymatic antioxidant activity and phytoremediation efficiency as affected by different Cd stress in the shoot of hyperaccumulator vetiver plant. Magnetized treatment was discovered to increase the Cd concentration and accumulation and subsequently activity of enzymatic on nonenzymatic antioxidant in the shoots. As a result, an increase in the Cd uptake and antioxidant content in Lantana camara plants of magnetized treatment stimulation is beneficial for phytoremediation.

Conclusion

This study aimed to investigate the effect of magnetic properties on the adsorption performance of cadmium heavy metals by Lantana camara plant from irrigation water, and three samples of magnetized water-semi-magnetic and non-magnetic water and different concentrations of cadmium-were analyzed. At first, the quality of the soil and water was measured, and finally, after a 6-month treatment period, different parts of the plant, including the roots and shoots, as well as the biochemical properties of the plant, were measured. The results showed that magnetization treatment of water or effluent could significantly improve the absorption of cadmium by the plant. In addition, by increasing the concentration of cadmium in irrigation water, the amount of absorption by the plant also increased. Finally, the results of this study indicate the high capacity of cadmium absorption by Lantana camara plant. Water magnetization operation can be used as an effective complementary method in the phytoremediation process to remove heavy metals from contaminated soil.

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