J. Soil Sci. and Agric. Eng., Mansoura Univ., Vol. 10 (4):245 - 251, 2019

Evaluation of Flax Plant as a Cadmium Phytoremediator for Polluted Soils under Different Chemical and Biological Treatments

Badawy, S. H.*; M. I. D. Helal and Amina M. H. Metwaly
Soil Sci. Dep., Fac. of Agric., Cairo Univ., Giza, Egypt
***Correspondence: shbadawy60@yahoo.com**

ABSTRACT

A pot experiments was carried out in the greenhouse of Faculty of Agriculture Cairo University during the two successive winter seasons (2015-2016 and 2016-2017) to evaluate the potential of flax plants (Linum usitatissimum L.) as a Cd tolerant and accumulator for polluted soils. The experiment was laid out in a split-plot design with a randomized-complete design in three replicates. Surface sandy loam soil samples (0-20 cm) were collected from Abou-Rawash area, which received sewage sludge and sewage effluent for long time (about 20 years).Three levels of soil Cd (initial 3.13), and two artificial ones 50 and 75mg kg^{-1} soil, were prepared using $CdCl_2$ solution by wet and dry process for three months. The chemical (EDTA) and biological (AMF and Thiobacillus) treatments were allocated to sub plots. Each sub plot consisted of pots each containing 10kg soil and 100 flax plants. The results showed that by increasing soil cadmium levels, the flax plant dry weight (roots, stem and leaves) significantly decreased. Under different levels of soil Cd, the chemical and biological treatments recorded variable changes in flax plant dry weight. The highest increases in dry weight was recorded with AMF treatment (5.63 and 8.50% in 1st and 2nd seasons, respectively, with an average of 7.06%) compared with the control (initial).However, cadmium contents in the different parts of flax plant increased with increasing soil cadmium levels. The highest Cd concentration in flax roots, stem and leaves recorded in EDTA treatment which lead to increases of 1.73, 2.11 and 1.88 folds in roots, stem and leaves, respectively, compared with untreated soil at 75 µg Cd g^{-1} soil. The uptake of Cd by flax substantially affected by both levels of Cd in soil and different soil treatments. The highest Cd uptake was found in 75 µg g^{-1} soil level followed by 50µg g^{-1} and the lowest in 3.13 µg g-^{1} soil. Flax was uptake and accumulate cadmium from the soil with distributing evenly throughout plants (roots > stem > leaves). Both EDTA and AMF treatments recorded the highest phytoextraction of Cd from contaminated soil. Finally, the obtained results suggest that, flax plant can be considered as a Cd tolerant which can accumulate Cd, especially, with mycorrhiza fungi and EDTA treatments but could not be considered a hyperaccumulator of Cd from polluted soils.

Keywords: Soil pollution, cadmium, heavy metals, phytoremediation, flax, EDTA, AMF

INTRODUCTION

The possibility of using crops as phytoremediants depends on the accumulation and distribution of metals among their morphological organs. Plants characterized by high biomass production and intensive heavy metals accumulation in shoots can be used as phytoremediants (Ebbs *et al*., 1997).

Cadmium is a heavy metal naturally present in soils. It may be also added to the soil as a contaminant in fertilizer, manure, sewage sludge and from aerial deposition. The amount of cadmium contributed from each source varies with location due to differences in soil formation, management practices and exposure to pollution sources, but as results the level of Cd in the soil appears to be increasing over time (Luo *et al*., 2005; Bhatti *et al*., 2007).

Phytoextraction is recommended as one option for reducing toxic metal content, as the technology is perceived to be ecofriendly, effective, and affordable (Shaheen and Rinklebe, 2015; Antoniadis *et al*., 2017). Phytoextraction heavy metals had received increasing attention in recent years as an alternative to physical and chemical methods of decontamination in which heavy metals accumulating plants and appropriate soil amendments were used to transport and concentrate heavy metals from the soil into the aboveground shoots (Nowack *et al*., 2006; Vamerali *et al*., 2012). Crops differ greatly for Cd that they contain and in the Cd distribution within particular plant parts. According to literature, flax and other fiber crops are considered as Cd-accumulator species because the substantial proportion of their production used for non-food purposes/products (Broadley *et al*., 2001; Angelova *et al*., 2004; Bjelkova, 2006). Shi and Cai (2009) reported that flax plant cultivated in the presence of 50-200 mg Cd kg^{-1} soil exhibited a limited reduction of growth also, innate resistance to Cd stress and is moderately tolerant.

Phytoextraction capacity of plants does not only depend on specific plant character like metal tolerance, accumulation and translocation, but also in soil factors which affect metal phytoavailability (Hernandez-allica *et al*., 2008; Douchiche *et al*., 2012). Using soil amendments like chemical amendment ssuchassynthetic organic chelates can enhance phytoextraction by increasing heavy metals bioavailability in soil thus enhancing plant uptake, and translocation from the roots to the green parts of plants (Marschner, 1995; Epstein *et al*., 1999; Shen *et al*., 2002).EDTA is the most effective chelating agent used for phytoremediation because it has a strong chelating ability for different metals and it increases the bioavailability and plant uptake of the metals in the soil (Liphadzi *et al*., 2003).Salt *et al*. (1998) and Sun *et al*. (2001) recommended application of EDTA on soil at the flowering or maturity stages, because solubilized metals and EDTA salt can be toxic to plants and thus hinder plant growth and phytoextraction of heavy metals. The addition of 0.5 or 2 g kg^{-1} EDTA increased Cd content in shoots of Populus sp. Plants, unfortunately, addition of EDTA with rate of 2 g kg^{-1} soil caused a significant plant growth reduction, as well as leaf abscission(Robinson *et al*., 2000).

Rhizosphere-microorganisms can promote phytoextraction of Cd via enhancing plant growth or by improving Cd-accumulation by plants. The most widely investigated species are fungi, especially AMF. This could be attributed to the fact that mycorrhizal-fungi have been known as the only type providing a direct connection between soil and plant-roots (Usman and Mohamed, 2009). Moreover, it is found that among various tested microorganisms AMF species exhibited the highest efficiency in increaqsing Cd-removal by the studied plant species. Thus, plant roots infected with mycorrhizal fungi get benefits due to increased growth (Birch and Bachofen, 1990).Mycorrhizae were have been reported to play a central role in improving plant tolerance to Cd-contaminated soils. This achieved by enhancing both growth of host plants and nutritive elements in plants (Huang *et al*., 2017).

The objectives of this study are to evaluate flax plant as cadmium phytoextracting capacity of polluted soils with different chemical (EDTA) and biological (mycorrhizal fungi, Thiobacillus *thiooxidans)* treatments.

MATERIALS AND METHODS

A Pot experiment was conducted in the greenhouse at the Faculty of Agriculture, Cairo University, Giza, during two consecutive winter seasons (2015-2016 and 2016-2017) to evaluate flax plants as a cadmium remediator from polluted soils. A polluted soil samples were collected from Abou-Rawash area, Giza, Egypt. These soils had received sewage sludge and sewage effluent for 20 years, with a background value of 3.13 mg total Cd kg^{-1} soil. The soils were air-dried, ground using wooden mortar, passed through a 2 mm sieve before use and prepared for analyses. The Particle size distribution (sand, silt and clay), soil texture, water-holding capacity (WHC), pH, EC, total $CaCO_3$, organic matter (OM), total and available nitrogen (N), phosphorus (P) and potassium (K) according to standard methods outlined by Keeney and Nelson (1982), and DTPA-extractable Cd according to method of Lindsay and Norvell (1978). Total Cd was measured using Aqua regia extraction methods (Cottenie *et al*., 1982). Cadmium concentration was measured by Atomic Absorption Spectrophotometer (AAS), perkin-Elemer AAnalst 400. The main soil properties are given in Table 1.

Table1. The main physical and chemical characteristics of soil used in the experiment.

Soil parameters	Seasons	
	1st season	2nd season
Particle size distribution		
Clay (%)	10.60	10.21
Silt (%)	13.20	13.94
Fine sand (%)	32.10	32.6
Coarse sand (%)	44.10	43.25
Texture class	Sandy loam	Sandy loam
Water holding capacity (v:v)%	15.42	15.33
Bulk density (gm\cm^3)	1.61	1.58
Organic matter (%)	3.53	2.89
Calcium carbonate (%)	1.66	1.58
EC (dS m^{-1})*	2.75	2.05
pH**	6.68	6.97
Total nitrogen (%)	0.195	0.191
Available nitrogen (mg kg^{-1})	133.2	114.6
Total phosphorus (mg kg^{-1})	1560	1458
Available phosphorus (mg kg^{-1})	55.10	35.21
Total potassium (mg kg^{-1})	2723	2704
Available potassium (mg kg^{-1})	593	487
Total cadmium (mg kg^{-1})	3.13	2.85
DTPA extractable-Cd (mg kg^{-1})	0.22	0.19

***measured in 1:2.5 soil: water extract**
****measured in 1:2.5 soil: water suspension**

Plastic pots (35 cm diameter) were filled with 10 kg air-dried soil, and soaked with solution of$CdCl_2$ at three levels: control (background level);50 and and 75 mg Cd kg^{-1}soil. Each soil Cd level had treated by seven treatments (T1= untreated;T2= Disodium Ethylene Diamine Tetra Acetic acid (Na_2EDTA);T3= Thiobacillus (Thio);T4= Arbuscular mycorrhizal fungi (AMF);T5= AMF+Thio; T6= AMF+EDTA and T7= AMF+EDTA+Thio) with three replicates per treatment.

The experiment laid out in a split-plot design in a randomized complete design (RCBD) arrangement with three replications. The main plots consisted of three levels of artificial polluted soil with Cd, where 250 mg L^{-1} $CdCl_2$ solution were slowly added to soil to increase the soil Cd concentration, while avoiding leachate release from the pots, then the soil was subjected to wetting and drying cycles for three months to allow Cd to reach chemical equilibrium. The seven treatments were allocated to sub plots. Each sub plot (experimental unit).Flax seeds were sown in each pot and kept at 100 flax plants. All agricultural practices were maintained normal and even for all of the treatments. EDTA used applied at a rate of 2g kg^{-1}, which added to soil at 60 days after plantation of flax plants. Inoculation with AMF was carried out by adding the peat based AMF inoculum containing 10^7spores g^{-1} to each pot at a rate of 10g/kg $soil^{-1}$. Five day old culture suspension of *Thiobusulsthioxidans* containing 10^7cells.ml^{-1} was used as liquid inoculant at a rate of 10 ml per pot.

Seeds of flax (*Linum usitatissimum* L.) were sown in each pot by pressing them into soil to a depth of 0.5 cm. The pots were watered to 70% of soil water holding capacity, then thinned out to 100 seedling per pot after 21 days and allowed to grow up to flowering stage. Flax plants were carefully harvested, washed with tap water, to remove any adhered particles, rinsed twice with distilled water, separated to roots, stem and leaves and oven dried at 70 ^oC to a constant weight. The weight of oven dried plant was measured. The oven-dried plant materials were ground using stainless steel mill and kept for chemical analysis. The ground oven dried plant was subjected to digestion using mixture of acid (HNO_3-H_2SO_4-$HCLO_4$) as described by Jackson (1973). Concentrations of Cd were measured in the digest solution by AAS. All analysis were done in duplicates. At the end of both the first and second seasons, soil samples were collected from all treatments from the middle of the pots to minimize the error of sampling. The soil were air dried, crushed, sieved through a 2 mm sieve and thoroughly mixed to determine the DTPA-extractable Cd and total content of Cd.

Statistical analysis: Statistical analyses of variance were carried out on the obtained results for each season and for all the studied parameters according to the procedure described by Snedecor and Cochron (1981). The Least Significant Differences test (LSD) at 5% level of probability was used to test the significance of differences among the means. The “MSTAT-C" software package was used to carry out these statistical analyses (Freed *et al*., 1989).

RESULTS AND DISCUSSION

Flax plant dry weight:

Soil cadmium levels affected markedly the dry weight of flax roots, stem, leaves and total biomass (Fig.1 and Table 2).

The highest DW was found in lowest soil Cd concentration (initial, 3.13 µg g^{-1} soil) and the lowest DW was found in plant grown in 75 µg g^{-1} soil level. This indicated that the higher Cd concentration in soil caused a significant growth reduction. Total DW of flax plant decreased by 27.96 and 31.37% as the Cd concentration in the soil increased (50 and 75 µg g^{-1}) when compared with the control. Cadmium can constrain metabolic pathways, such as transpiration, respiration and photosynthesis (Chugh and Sawhney, 1996, 1999; Di Cagno *et al*., 2001).

Data of Fig.1 and Table 2 show that under different levels of soil Cd, the chemical and biological soil treatments recorded variable changes in flax plant DW. Plants were greatly influenced by AMF inoculation ,achieving a higher biomass compared to untreated ones. The highest increases in DW was recorded in flax plants with mycorrhizal fungi treatment (5.63 and 8.50% in 1st and 2nd seasons, respectively, with an average 7.06%) comparing inoculated (initial) treatment. This may be due to flax plants grow symbiotically with mycorrhizal fungi which affected positivly root biomass. This might be attributed to the beneficial effect of the AMF symbiosis with flax plants which results in plant growth promoting effects. It also increased that the capability of the root-system to absorb proper nutrients from the soil. However, total DW of flax decreased in other soil treatments compared with initial soil without treatment. Birch and Bachofen (1990) regarding the beneficial effects of AMF symbioses on plant protection against several biotic and abiotic stresses as well as the plant growth promotion due to enhanced nutrient and water uptake by the mycorrhizal plants.

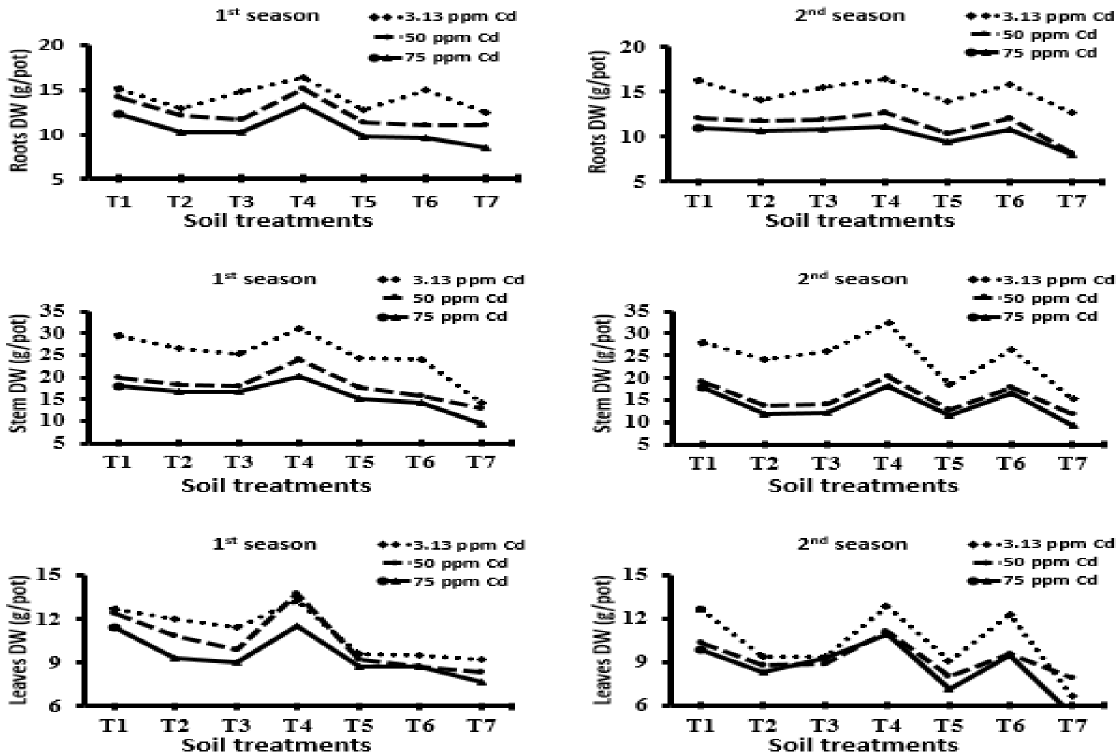

Fig. 1. Dry weights of roots, stem and leaves of flax plants as affected by different soil Cd-contents, biological and chemical amendments in both seasons.

Table 2. Total dry weight of flax plants as affected by different soil Cd-contents, biological and chemical amendments.

Treatments	Flax total dry weight (g/pot)					
	1st season			2nd season		
	Soil Cd concentration (mg kg^{-1})					
	3.13	50	75	3.13	50	75
T1	57.35	46.38	41.64	56.94	41.45	38.48
T2	51.50	41.47	36.34	47.74	34.25	31.01
T3	51.59	39.61	35.80	50.88	34.85	32.33
T4	60.77	52.74	45.17	61.78	44.20	40.04
T5	46.75	38.30	33.76	41.56	31.28	28.13
T6	48.54	35.55	32.54	54.32	39.41	36.86
T7	35.79	32.23	25.64	34.70	27.83	22.91
LSD at 0.05	30.7			2.08		

T1 = control; T2 = EDTA; T3 = Thio; T4 = AMF; T5 =AMF+Thio; T6 = AMF+EDTA; T7 = AMF+EDTA+Thio.

Cadmium concentration in Flax plant:

As shown in Fig. 2, the existence of Cd in the soil significantly-increased the concentration of Cd in the leaves, stems and roots of flax plants. Plant grown in high Cd soil recorded more Cd than did plant grown in low Cd soils. He *et al*. (2007) stated that soils that have higher concentrations of Cd up to 50-100 µmole CdL^{-1} would not be appropriate for use over long periods. This is because the growing plants would probably not survive these higher concentrations. Our data showed that, the concentration of Cd remarkably varied among the different parts of flax plant, where the roots have the highest concentration. The highest Cd concentration in roots (36.28 and 28.82 µg g^{-1} DW in 1st and 2nd seasons, respectively) was found in soil containing 75 µg Cd g^{-1} soil, which represented 1.26 and 8.21 folds at the same treatment in in soil containing 50 and 3.13 µg Cd/g soil, respectively.

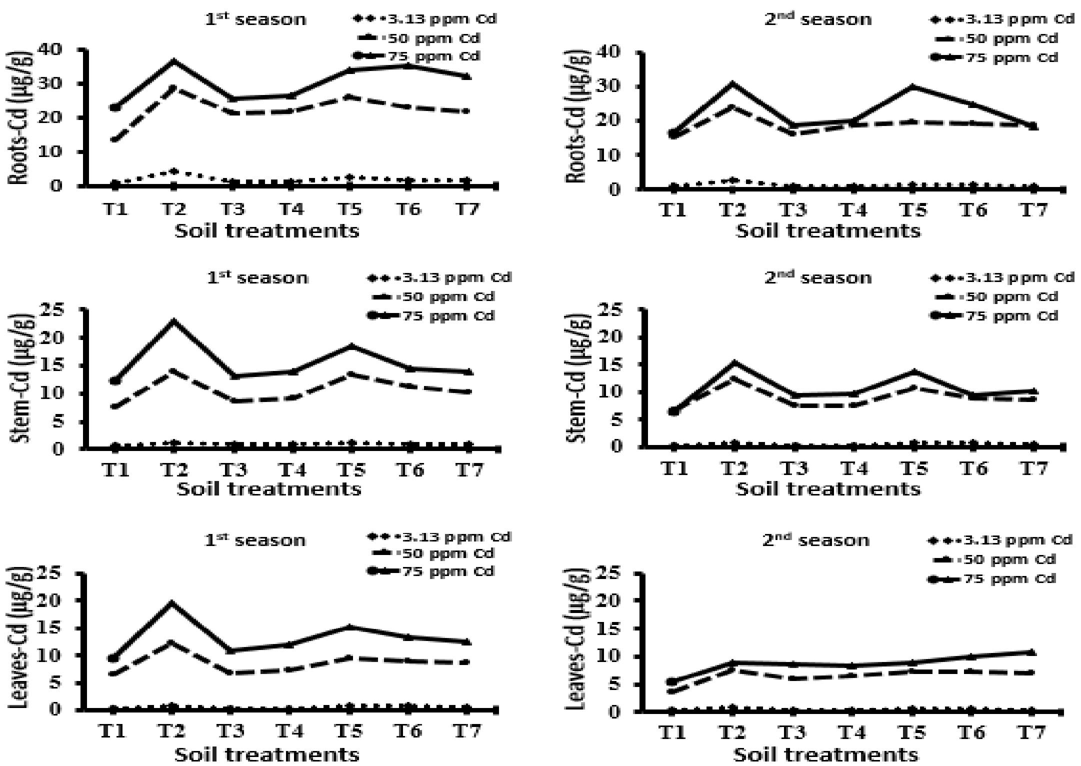

Fig. 2. The relationship between soil treatments and soil cadmium levels and leaves Cd concentrations in roots, stem and leaves of flax plant grown in the two seasons.

The Cd concentrations in both of stem and leaves were less than roots and significantly correlated (R^2= 0.95 and 0.91) with Cd concentration in roots (Fig. 3).

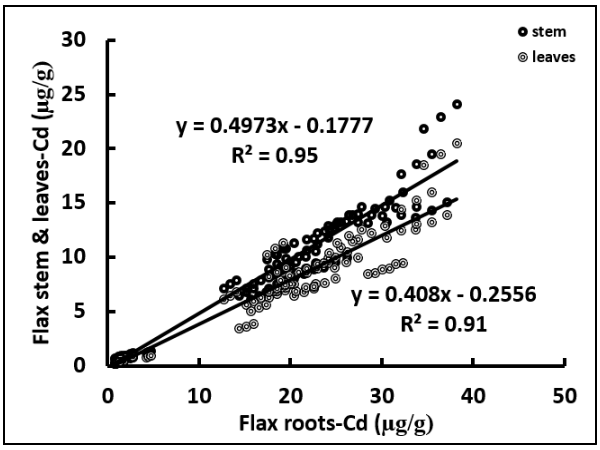

Fig. 3. The relation between concentrations of Cd in flax stem and leaves and roots of flax plant.

The concentration level decreased in the following order: roots >stem> leaves. The obtained results agree with the found by Straczynski(2000); Stritsis and Claassen (2013), who reported that different distribution of Cd in plant parts due to the mobilization of such protective mechanisms of plants, which inhibits the transport to further tissues and organs.

Fig.4 showed that under different levels of soil Cd, the different soil treatments recorded variable changes in Cd concentration in flax plant organs. Generally, the highest Cd concentration in flax roots, stem and leaves was in the order: EDTA>AMF+EDTA>AMF+Thio> Thio> AMF > AMF+EDTA+Thio treatments. This increases were; 1.73, 1.64, 1.52, 1.11, 1.20, 1.26 folds in roots; 2.11, 1.82, 1.32, 1.26, 1.30, 1.36 folds in stem; 1.88, 1.63, 1.62, 1.38, 1.40, 1.67 in leaves, as compared with untreated soil contains 75 µg Cd g^{-1} soil. These data cleared that the flax is trouble but not hyperaccumulator plant for Cd according to Reeves and Baker (2000), who reported that concentration of Cd 100 mg kg^{-1} dry weight has been used as a criteria for hyperaccumulation plant. In addition to biomass production, heavy metals concentration is the most important factor, determining the feasibility of metallophytes for successful phytoremediation (Bennett *et al*., 1998; Rajkumar *et al*., 2012).

Cadmium uptake by plant:

Soil cadmium levels affected Cd uptake and accumulation by plant roots, stem, leaves and total uptake, which were different for plants grown in soil enriched with Cd (Fig. 5 and Table 3). The results cleared that the highest Cd uptake was found in 75 µg g^{-1} soil followed by 50 µg g^{-1} then the lowest in 3.13 µg g^{-1} soil. Fax plants take up and accumulate cadmium from the soil which are not distributed evenly throughout plants. Roots contained the high amount of cadmium (ranged from 33.6 to 59.0 within an average 50.2% from total Cd uptake) followed by stem (ranged from 26.2 to 50.4 within an average 34.9% from total Cd uptake) then leaves (ranged from 8.4 to 20.2 within an average 14.7% from total Cd uptake). The relatively high accumulation of cadmium in root tissue and the minimal transfer of cadmium from roots to shoots have been documented by Huang *et al*. (2017).

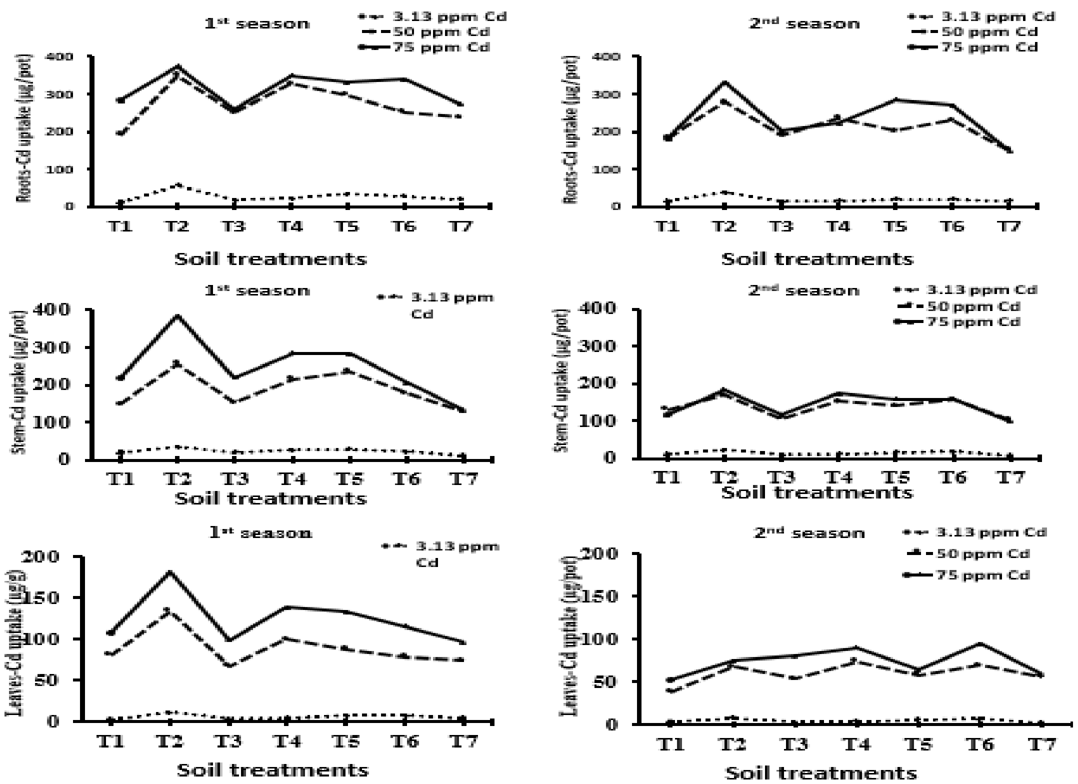

Fig. 4. Effects of soil treatments and soil cadmium levels on Cd uptake by flax roots, stem and leaves in two seasons.

Table 3. The effect of Cd levels in polluted soil and different soil treatments on flax total Cd uptake in both seasons.

Treatments	Cd uptake (µg/pot)					
	1st season			2nd season		
	Soil Cd concentration (mg kg^{-1})					
	3.13	50	75	3.13	50	75
T1	34.83	420.16	609.94	26.17	350.97	348.82
T2	101.85	741.66	941.34	66.36	515.99	588.78
T3	42.70	471.25	578.15	25.59	349.75	396.56
T4	54.87	642.23	772.83	31.82	463.09	484.41
T5	68.88	621.33	747.23	41.30	398.96	507.70
T6	58.79	508.90	659.24	45.02	455.23	523.72
T7	36.64	441.71	501.38	25.81	308.33	303.12
LSD at 0.05		14.06			9.99	

T1 = control; T2 = EDTA; T3 = Thio; T4 = AMF; T5 =AMF+Thio; T6 = AMF+EDTA; T7 = AMF+EDTA+Thio.

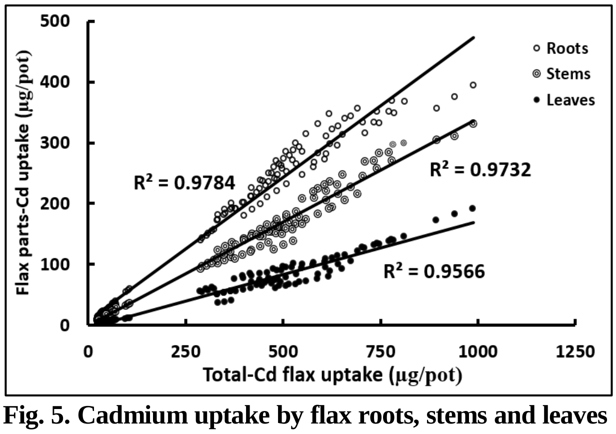

Fig. 5. Cadmium uptake by flax roots, stems and leaves as a function of total Cd uptake.

The effect of different soil treatments on Cd removed from soil and uptake by plant is represented in Fig. 5 and Table 3.The highest Cd uptake by flax grown in 75 µg g-1 soil recorded EDTA treatment (941.34 and 588.78 µg/pot in the first and second season, respectively). Cadmium uptake by flax under different soil treatments compared with untreated soil represented an average of: 1.87 fold EDTA; 1.46 fold AMF+EDTA; 1.35 fold AMF+Thio; 1.30 fold AMF, 1.03 fold Thio and 0.88 fold AMF+EDTA+Thio treatments. These results agree with those found by Angelova, (2004), who reported that Cd phytoextraction is always less certain which are largely due to the fact that Cd in soils is usually readily bioavailable. Flax Cd uptake in both seasons was found to follow the order: roots > stem > leaves, associated with a significant relationships (R2 = 0.978, 0.973 and 0.957) between roots, stem and leaves with total flax Cd uptake, respectively (Fig. 5).

Recovery of soil Cd by flax uptake:

Geochemical forms of heavy metals in soil affect their solubility, which directly influence their bioavailability (Xian and Shokohiford, 1989). Therefore, determining total content of heavy metals in soil is insufficient to assess the environmental impact of contaminated soils. A part of this study was to investigate the effect of total, DTPA extractable-Cd on Cd uptake percentage and recovery by flax plants. Figure 6 and 7cleared that, generally, the highest Cd uptake percentage from total soil Cd content was found in 3.13mg/kg soil level (0.19-0.54%) followed by 50 mg/kg (0.17-0.29%) then the lowest in 75mg/kg soil (012-0.22%).Soil Cd levels and different soil treatments had a significant effect on Cd uptake percentage from total soil Cd content in both seasons which decreased with increasing soil Cd levels. The highest Cd uptake percentage from total soil Cd content (0.33%) was in lowest soil Cd concentration level (initial, 3.13 mg/kg soil) with EDTA treatment and lowest one (0.05%) was found in AMF+EDTA+Thio treatment with 75 mg Cd/g soil level in second season.

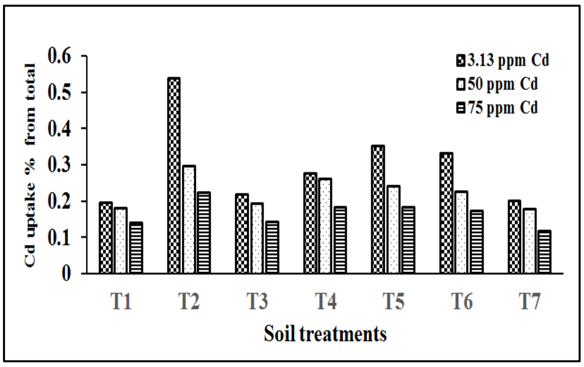

Fig. 6. Cadmiumuptake by flax plant as a percentage of soil total Cd under different soil treatments.

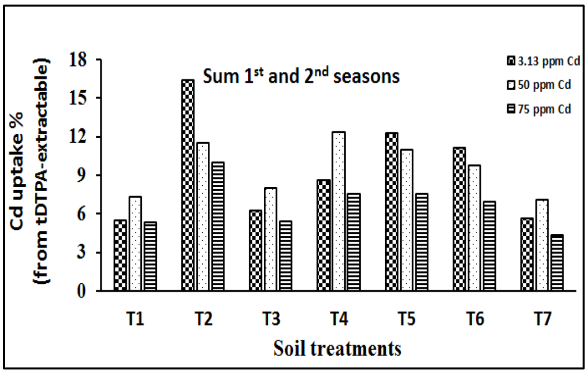

Fig.7. Cadmium uptake by flax plants as a percentage of DTPA extractable-Cd under different soil treatments.

Based on these data, DTPA extractable-Cd is more bioavailable than metals associated with the residual fraction. Theses cleared that the highest Cd uptake percentages from DTPA extractable- Cd found in 3.13 mg/kg soil level were 4.38 and 5.02% followed by 50 mg/kg soil and were 4.20 and 5.38% then the lowest was in 75 mg/kg soil were 3.74 and 3.50% for 1st and 2nd seasons, respectively. Also, the average of percentage of Cd uptake at all treatments, recorded the value in first season, varied from 2.85 to 5.98 with an average 3.94% less than the second one which recorded from 2.85 to 6.64 with an average 4.63%.The highest percentage was found in EDTA treatment. This may be due to increase of soluble Cd form in soil. Also, the results showed that, in different soil treatments, Cd uptake percentage was significantly influenced. The summations of Cd uptake for two season was from 5.71 to 12.64 with an average by 8.57%. The highest increases were recorded in EDTA treatment comparing with other treatments.

CONCLUSION

Flax is the crop that could extract and accumulate Cd from the soil. Cadmium distribution along the plant axis of flax is selective and decreasing in the following order: roots >stems >leaves. Flax plant can be recommended as a suitable crop for growing in Cd polluted soil, as it is removes considerable amounts of Cd in roots and can be used as potential crop for cleaning soil from Cd.

ACKNOWLEDGMENT

This research work was part of M.Sc. thesis entitled "use of flax plant for remediation of cadmium polluted soil". The authors would like to thank Prof. Dr. Mohamed. Abdelalim Ali, Professor of Microbiology Dept. of Microbiology, Fac. of Agric., Cairo Univ., Giza, Egypt for his unlimited support during this study. Also, express deepest thanks to Prof. Dr. M. Abdelmaboud, Professor of Statistics, Dept. Agron., Fac. of Agric., Cairo Univ, for his technical support in carrying out the statistical analyses.

REFERENCES

Angelova, V.; Ivanova, R.; Delibaltova, V. and Ivanov, K. (2004). Bio-accumulation and distribution of heavy metals in fibre crops (flax, cotton and hemp). Ind. Crops Prod. 19, 197-205.

Antoniadis, V.; Levizou, E.; Shaheen, S.M.; Ok, Y.S.; Sebastian, A.; Baum, C.; Prasad, M.N.V.; Wenzel, W.W. and Rinklebe, J.(2017). Trace elements in the soil plant interface: Phyto availability, translocation, and phyto remediatione A review. Earth Sci. Rev. 171, 621-645.

Bennett, F.; Tyler, E.; Brooks, R.; Gregg, P. and Stewart, R. (1998). Fertilization of hyperaccumulators to enhance their potential for phytoremediation and phytomining. Plants Hyperaccumulate Heavy Metals Role Phytoremed., Microbiol. Archaeol. Mineral Explor. Phytomin. 249-259.

Bhatti, H.N.; Mumtaz, B.; Hanif, M.A. and Nadeem, R. (2007). Removal of Zn (II) ions from aqueous solution using *Moringa oleifera* Lam. (horseradish tree) biomass. *Process Biochem.*, 42: 547–553.

Birch, L. D. and Bachofen, R. (1990). Effects of microorganisms on the environmental mobility of radionuclides. In J. M. Bollang and G. Stozky [eds.], Soil Biochemistry, 483–527. Marcel Dekker, New York, New York, USA.

Broadley, M.R.; Willey, N.J.; Wilkins, J.C.; Baker, A.J.M.; Mead, A. and White, P.J. (2001). Phylogenetic variation in heavy metal accumulation in angiosperms. New Phytol.152: 9-27.

Chesworth, W. (1991). Geochemistry of micronutrients. In J. J. Mortvedt, F. R. Cox, L. M. Shuman, and R. M. Welch [eds.], Micronutrients in agriculture, 2nd ed., 1–30. Soil Sci.Soc. Am., Madison, Wisconsin, USA.

Chugh, L. K. and Sawhney, S. K. (1996). Effect of cadmium on germination, amylases and rate of respiration of germinating pea seeds. Environ. Pollut. 92: 1-5.

Chugh, L. K. and Sawhney, S. K. (1999). Photosynthetic activities of Pisum sativum seedlings grown in presence of cadmium. Plant Physiol. and Biochem. 37: 297- 303.

Cottenie, A.; Nerloo, M.; Velghe, G. and Kiekens, L. (1982). Biological and analytical aspects of soil pollution. Lab. of Analytical Agro. State Univ. of Calif. Division of Agric. Sci.: 60-69.

Di Cagno, R.; Guidi, L.; De Gara, L. AND Soldatini, G. F. (2001).Combined cadmium and ozone treatments affect photosynthesis and acerbate dependent defenses in sunflower. New Phytologist 151: 627- 636.

Douchiche, O.; Chaïbi, W. and Morvan, C. (2012). Cadmium tolerance and accumulation characteristics of mature flax, cv. Hermes: contribution of the basal stem compared to the root. J. Hazard. Mater 235: 101-107.

Ebbs, S. D.; Lasat, M. M.; Brady, D. J.; Cornish, J.; Gordon, R. and Kochlan, L. V. (1997).Phytoextraction of cadmium and zinc from a contaminated soil. J. Environ. Qual. 26 (5), 1424-1432.

Epstein, A. L.; Gussman, C. D.; Blaylock, M. J.; Yermiyahu, U.; Huang, J. W.; Kapulnik, Y. and Orser, C. S. (1999). EDTA and Pb-EDTA accumulation in Brassica juncea grown in Pb-amended soil. Plant and Soil. 208: 87–94.

Freed, R. S. P.; Eisensmith, S.; Goetz, D.; Reicosky, V.; Sma, W. and Wolberg, P. (1989). User's Guide to MSTAT-C: A Software Program for the Design, Management and Analysis of Agronomic Research Experiments, Michigan State University, East Lansing, ML, USA.

Hernandez-allica, J.; Becerril, J. M. and Garbisu, C. (2008). Assessment of the phytoextraction potential of high biomass crop plants. *Environ. Pollut*., 152: 32-40.

Huang, X.; Ho, S.; Zhu, S.; Ma, F.; Wu, J.; Yang, J. and Yang, L. (2017).Adaptive response of arbuscular mycorrhizal symbiosis to accumulation of elements and translocation in Phragmites australis affected by cadmium stress. Journal of Environ. Manage. 197: 448-455.

Jackson, M. L. (1973). Soil Chemical Analysis, Prentice Hall of India Pvt. Ltd. New Delhi.

Keeney, D. R., and Nelson, D. W. (1982).Nitrogen-Inorganic forms. NOTES 553p. 643- 698. *In* A.L. Page *et al*. (ed .) Methods of Soil Analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison,WI.

Lindsay, W. L. and Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci. Soc. of Am. J. 42: 421-428.

Liphadzi, M. S.; Kirkham, M. B.; Mankin, K. R. and Paulsen, G. M. (2003). EDTA assisted heavy metals uptake by poplar and sunflower grown at a long-term sewage-sludge farm. Plant Soil, 257: 171-182.

Luo, C.L.; Shen, Z. and Li, X. (2005). Enhanced phytoextraction of Cu, Pb, Zn and Cd with EDTA and EDDS. *Chemosphere*, 59: 1-11.

Luo, C. L.; Shen, Z. G.; Lou, L. Q. and Li, X.D. (2006). EDDS and EDTA-enhanced phytoremediation of metals from artificially contaminated soil and residual effects of chelate compounds. Environ. Pollut. 144: 862-871.

Marschner, H. 1995. Mineral Nutrition of Higher Plants. 2nd Ed. Academic Press: London.

Nowack, B., R. Schulin and B.H. Robinson, 2006. Critical assessment of chelant-enhanced metal phytoextraction. *Environ. Sci. Technol*., 40: 5525−5532

Rajkumar, M.; Sandhya, S.; Prasad, M. and Freitas, H. (2012). Perspectives of plant associated microbes in heavy metal phytoremediation. Biotechnol. Adv. 30,1562-1574.

Reeves, R. and Baker, A. (2000) Metal accumulating plants. In Phytoremediation of Toxic Metals: Using Plants to Clean Up the Environment. Raskin, I. and Ensley, B., Eds. John Wiley & Sons, New York. pp. 193-229.

Robinson, B. H., Brooks, R R, & Clothier, B. E. 1999, "Soil amendments affecting nickel and cobalt uptake by Berkheya coddii: Potential use for phytomining and phytoremediation", *Annals of Botany*, vol. 84,no. 6, pp. 689-694.

Salt, D. E.; Smith, R. D. and Raskin, I. (1998). Phytoremediation. Annual Review of Plant Physiology and Plant Molecular Biology 49, 643-668.

Shaheen, S.M. and Rinklebe, J. (2015). Phytoextraction of potentially toxic elements by Indian mustard, rapeseed, and sunflower from a contaminated riparian soil. Environ. Geochem. Health 37: 953-967.

Shen, Z.G., Li, X.D., Wang, C.C., Chen, H.M., and Chua, H. (2002). Lead phytoextraction from contaminated soil with high biomass plant species. J. Environ. Qual., 31, 1893-1900.

Shi, G. and Cai, Q. (2009). Cadmium tolerance and accumulation in eight potential energy crops. Biotechnol. Adv. 27, 555–561.

Snedecor, G.W. and Cochron W.G. (1981). Statistical Methods 7th ed. Iowa State Univ., Press, Ames, Iowa.

Straczynskis, J. (2000). Cadmium content in selected plant species cropped on copper polluted soils. Zesz. Nauk. Kom. "Cz3owiek i OErodowisko" 26, 233, (In Polish).

Stritsis, C. and Claassen, N. (2013).Cadmium uptake kinetics and plants factors of shoot Cd concentration. Plant Soil 367:591-603.

Sun, B.; Zhao, F. J.; Lombi, E. and McGgrath, S. P. (2001). Leaching of heavy metal from contaminated soils using EDTA.Environ. Pollut., 113:111-120.

Usman, A.R.A. and Mohamad, H. M. (2009). Effect of microbial inoculation and EDTA on the uptake and translocation ofheavy metal by corn and sunflower. Chemosphere 76:893-899.

Vamerali, T.; Marchiol, L.; Bandiera, M.; Fellet, G.; Dickinson, N. M.; Lucchini, P. and Mosca, G.(2012). Advances in agronomic management of phytoremediation; methods and results from a 10-year study of metal-polluted soils. Ital. J. Agron., 7: 323-330.

Xian, X. and Shokohiford, G. (1989). Effects of pH on chemical forms and plant availability of cadmium, zinc and lead in polluted soils. *Water Air Soil Pollut*., 47: 265−273.

إستخدام نبات الكتان لمعالجة الاراضى الملوثة بالكادميوم باستخدام بعض المعاملات الكيميائية و الحيوية المختلفة

السيد حسن بدوى ، محمد إبراهيم دسوقى هلال و أمينة متولى حسين
قسم الاراضى ـ كلية الزراعة ـ جامعة القاهرة

أقيمت تجربة أصص خلال الموسمين (2015-2016 و 2016-2017) فى الصوبة الخاصة بكلية الزراعة ,جامعة القاهرة , و ذلك لتقييم إمكانية إستخدام نبات الكتان لمعالجة التربة الملوثة بعنصر الكادميوم و التحقيق من أنه متحمل لهذا العنصر. تم تجميع العينات من مزرعة أبو رواش على أعماق (صفر-20 سم) والتى تستقبل الحمأة الزراعية عن طريق الرى لفترات طويلة بمياه الصرف الصحى لمدة 20 عاما.ثلاث مستويات من الكادميوم فى التربة (3.13 و هى العينة المبدئية) وأيضا عيناتان ملوثتنان صناعيا وكان تركيز الكادميوم فيها 50 و 75 مجم\كجم$^{-1}$ و التى تم تجهيزهذه العينات بإستخدام كلوريد الكادميوم بالترطيب و التجفيف لمدة ثلاثة أشهر . المعاملات الكيميائية فى حين كانت المعاملات الحيوية .و تم تقسيم العينات فى أصص و أحتوى كل أصيص على 10 كجم من التربة و 100 نبات من الكتان . و أظهرت النتائج أنه بزيادة مستويات الكادميوم فى التربة ,حدث إنخفاض ملحوظ فى الوزن الجاف للجذور ,السيقان, و الاوراق .و تحت تركيزات منخفضة من الكادميوم فى التربة . و أوضحت النتائج أن نبات الكتان يعتبر من النباتات المتحملة للكادميوم و الذى يمكنه تجميع الكادميوم فى أجزاءه , خاصة , مع معاملة الميكروهيزا ولكن لا يمكن إعتباره فائق التحمل للكادميوم من الاراضى الملوثة.