International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS)
Volume VIII, Issue VII, July 2019 | ISSN 2278-2540

Quantifying Heavy Metal Extraction Potentials of Castor (*Ricinuscommunis L.*) and Cotton (*Gossypiumhirsutum L.)* from Soil

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Abstract: - **Several surface inland water bodies and groundwater are now being polluted by toxic heavy metals as a result of polluted soils in the environment. Surface water bodies become polluted as a result of runoffs from polluted soils and groundwater polluted as a result of leaching from polluted soils. This is now a major concern especially in the fisheries and aquaculture sector which mainly depends on surface and groundwater for productions because these metals cause water pollution and poses various forms of adverse effects on aquatic organisms; they accumulate in their tissues thereby contaminating the food chain when consumed by higher animals. Keeping in view the gravity of such environmental problem, a pot experiment was undertaken to study and quantify the potentials of metal accumulation and the distribution pattern in castor and cotton which are non-edible, commercial and industrial plants grown on heavy metal contaminated soil. Soils were treated separately with two levels of metals: Ni,Cr,Pb and Cd, at 50 and 100 ppm and also a combination of all metals at 50 and 100ppm in a completely randomized design experiment. A set of crops grown on soil with no metal amendment served as the control. Both crop species showed a remarkable difference in accumulation, uptake and distribution of these metals in their different plant parts. In general, the pattern of total metal accumulation in both crops followed the order Pb>Ni>Cr>Cd. The accumulation was also found to increase proportionately as the concentration of metals in soil increased. Combination treatments showed significant reduction in all metal accumulation in both crops when compared with the accumulation under a single metal contamination. Metal uptake was crop specific whereby Ni and Pb uptake was higher in castor while Cr and Cd were higher in cotton. Metal distribution in castor plant parts followed the order Stem>Leaf>Root>Seedshell>Seed; while in cotton it followed the order Bollshell>Stem> Leaf>Root>Seed>fibre. Distribution of almost all the metals was found to be more in vegetative parts compared with reproductive parts for both crops. Within the reproductive parts, pericarp (seed shells and boll shells) recorded maximum distribution as compared to economic parts (seed and fibre). This will help reduced surface water pollution as a result of run-offs from polluted soil and also groundwater pollution due to leaching of these heavy metals making it suitable for aquaculture purposes without contaminating the economic parts of the selected crops. Although both the plant species are hyper-accumulators, castor could be recommended where Ni and Pb are dominant pollutants and Cotton for Cr and Cd contaminated soil.**

Key words: **Heavy metals, Soil contamination, Run-offs, Leaching, Water pollution.**

I. INTRODUCTION

Soil contamination is a major environmental concern as industrial, agricultural and urban wastes generated from various human activities are being carelessly dispersed. The ecosystem is being contaminated as a result of uncontrolled disposal of such wastes. Heavy metal is a major part of in-organic contaminants and poses more severe problems than those of organic contaminants. Organic contaminants are degradable by soil microbes but heavy metals needs to be physically removed or mobilized by any possible means from the environment. Henry, 2000 has reported that even though metals are essential elements, they become toxic when available at high concentrations as they are able to cause several adverse effects on living organisms. Heavy metals such as lead, mercury, cadmium, arsenic, nickel, copper and chromium threatens the food chain. Jarup*et al*., 2009 has reported that these heavy metals are able to accumulate in soil from the use of phosphatic fertilizers, herbicides, and effluents from industries, sludge from municipal wastes, and the use of urban composts in crop production. Once the soil is polluted with these heavy metals, they find their ways into surface water through run-offs or to the groundwater through leaching and once these water are being used for aquaculture purposes, the metals become accumulated into aquatic organisms thereby contaminating the food chain (Akpan *et al.,* 2012).

Even though human health is at a great risk, many researchers have been using and still recommends some edible crop type to remediate contaminated environment. (Vamerali*et al*. 2010). The fact is that heavy metal contamination problem will still be same by using edible crops as phyto-remediation agents. These crops will be fed on by human or animals in one way or the other, this will introduce such metals into the food chain. From this we can conclude that the scientific community still lacks a safe technology without neglecting health risk when considering an effective heavy metal removal by plants from polluted sites. Several Non-edible plants are cultivated for the purpose of producing bio-fuels, lubricating and brake oils, fibre bags and clothing materials among several other products. These plants are not directly consumed by man or animals the way other crops such as cereals, vegetables and pulses are consumed.. These plants are considered as better options for phyto-remediation purpose. Non-edible plants such as jute, cotton, jathropha, castor etc, may be considered for this purpose as they are resistant in nature. The biomass can be collected and subsequently processed for recovery of heavy metals.

Therefore, considering the significance of above problem, this present research is aimed to propose a safer, more-economically feasible and more-eco-friendly approach for phyto-remediation using non-edible plants with an objective to quantify the heavy metal extraction potentials of castor and cotton plants from metal contaminated soil.

II. MATERIALS AND METHODS

Experimental site and set-up

A pot experiment was set up in the premises of glass house at the Centre for Environmental Science and Climate Resilient Agriculture, Indian Agricultural Research Institute New Delhi which is situated at 27^o 25'N latitude and 77^o 13'E and an altitude of 229.5 m above sea level between April to October 2015. Plastic pots were filled with sandy loam soil of 20kg each. Cotton and Castor plants were grown in amended soil with selected metals at two levels of concentration (50 ppm and 100 ppm) *i.e* Nickel, Lead, Cadmium and Chromium separately and also in a combination of all selected metals. These metals were selected because of their importance and occurrence in the food chain. Control pots were maintained without amendment with any metals. Crops were sown 20days after soil amendment with metals. All required agronomic practises to maintain a healthy growth of crops were ensured. The experiment was conducted in Completely Randomized Design and all treatments replicated four times.

Heavy metal amendment of soil

Artificialamendment of soil with the selected metals was done at two levels by applying their respective sulphate salts in soil as shown below (Table 1) considering the recommended maximum allowable limits for heavy metals (Kabata-Pandias, 2001). A set of pots amended with mixture treatment of all metals was also kept. Control pots were maintained which was not amended with any metal. The soils in the pot were thoroughly mixed after incorporating the metal salts followed by light irrigation. Thorough mixing and irrigation was done so as to ensure proper mixing and uniform distribution of heavy metals in the soil for about 20days before sowing of crops.

Table 1. Experimental treatments

Heavy metal	**Salt used**	**Conc. Level 1 (ppm)**	**Conc. Level 2 (ppm)**
Nickel(Ni)	$NiSO_4.7H_20$	50	100
Cadmium(Cd)	$CdSO_4.8H_2O$	50	100
Lead(Pb)	$PbSO_4$	50	100
Chromium(Cr)	$Cr_4(SO4)_5(OH)_2$	50	100
Ni+Cd+Pb+Cr	Combined	50	100
Control(Without Metal)	-	-	-

Samples collection and preparation

Soil samples

Soilsamples were collected from the top (0-15cm) layer of the pots, both before and about 20days after metal amendments *i.e* just before transplanting seedlings. The soil samples were air dried and crushed using mortar and pestle and sieved through 2mm sieve. The sieved samples were used for analyzing different parameters in order to investigate the relationship between these physical and chemical parameters and heavy metal bio - availability in the soil. The original soil characteristics in terms of pH and organic carbon were observed and recorded. The total and available metal content in samples were also analysed before and also after amendment with metals. This will give information about their contribution to the heavy metal contamination as observed in the plants tissues after their harvesting and analysis.

Plant Samples

Plant leaves were picked and air dried at various growth stages as they mature and fall off the plants. Following harvesting the crop at their maturity, various plant parts i.e. root, stem, leaf, fruit, seed, fibre and fruit shell were separated, collected and dried at 60^o C for 56 hours in hot air oven along side with the earlier picked matured leaves. After complete drying, plant samples were grounded in sample grinder to smooth textured powder for analysis

Physic-chemical analysis of soil samples

The pH, CEC, Organic carbon content and Available NPKof soil samples were measured and recorded following the standard procedures.

Estimation of heavy metals in soil

Total metal content in soil samples

The estimation of total heavy metals in soils (Ni, Cr, Pb, Cd) was determined following the procedures described by Singh *et al* (1999). The powdered form of all air dried collected soil samples were digested in di-acid mixture (Nitiric acid and Perchloric acid mixture in ratio of 9:4 respectively). A unit quantity i.e 1g each of all collected samples were taken into conical flask followed by adding 15ml of di-acid mixture into the same and was heated on hot plate till the colour changes from brownish to colourless. After cooling, the digested materials were filtered through a Whatman filter paper No.42. The volumes were made up to 50ml. The heavy metal content was determined using the Atomic Absorption Spectro-photometer (AAS).

Available metal content in soil samples

The estimation of available heavy metals in soils (Ni, Cr, Pb, Cd) was determined following the procedures described by Singh *et al* (1999). Extraction by DTPA-$CaCl_2$-TEA was followed. DTPA extraction reagent was prepared by dissolving 1.967g of diethyline-triamine-penta acetic acid and 1.47g of $CaCl_2.2h_2O$ in 25ml of double distilled water by adding 13.3ml of triethanol (TEA) followed by 100ml of double distilled water. Solution was then transferred to 1000ml volumetric flask. Before making up the volume, pH was adjusted to 7.3 with dilute HCl. The final solution contains 0.005M DTPA, 0.1M TEA and 0.01 M $CaCl_2.2H_2O$. 10gram each of the collected soil samples were taken into 100ml of conical flask and 20ml of DTPA extracting reagent was added to each flask. The flasks were shaken at 120 rpm for two hours on a mechanical shaker and then filtered through Whatman No.42 filter paper. Filtrates were made up to 20ml and directly used for the estimation of available metal content using Atomic Absorption Spectro-photometer (AAS).

Estimation of heavy metals in plants

Digestion of plant samples

Thiswas the first step involved in the process of heavy metal analysis of plant sample. Di-acid (Nitric acid and perchloric acid in 9:4 ratio) digestion was done (Singh *et al* 1999). 1g of each plant sample were weighed on a sensitive electronic balance and transferred into 150ml capacity conical flasks. 15ml of concentrated nitric acid was added and the samples was kept overnight for pre-digestion. 15ml of di-acid mixture (Nitric acid and Perchloric acid in ratio 9:4) was added into each conical flask containing the pre-digested plant samples and was digested on hot plates in the digestion chamber till contents becomes colourless and white dense fumes appeared. It was the allowed to cool and 20-25ml of double distilled water was and then filtered using Whatman No.42 filter paper into 50ml volumetric flasks and volumes made up to 50ml.

Estimation of metals in digested samples

This was done accordingly to the procedure described by Prasad *et al* (2006). Thecontents of heavy metals (Ni, Cr, Pb, Cd) in the digested and filtered samples were estimated using the Atomic Absorption Spectro-photometer (AAS) (Model: ECIL AAS 4141). Recorded values of metals obtained in ppm were multiplied by the dilution factor to find out the actual concentration of metals in plant samples.

Estimation of heavy metal uptake by plants and distribution in plants

The total fresh weight and dry weight of each plant part per pot was recorded so as to estimate the total metal uptake by each crops per pot. Metal uptake in each plant part was calculated by multiplying dry weight of plant part and metal content accumulated in the respective plant part. A comparison of metal content in the treated with the plants in the control pots accounts for an estimate of the mode of metal contamination which can either be by aerial deposition or absorption by plant roots. The metal distribution pattern was calculated by dividing the metal uptake in different parts with total metal uptake by plant and expressed in percentage.

III. RESULTS

Physico-chemical properties of soil

The physico-chemical properties of soil in terms of pH, organic carbon content, CEC, Available N, Available P, and Available K were estimated and recorded (Table 2). These information are necessary so as to better understand the dynamics of the metal treatment in terms of available and total content and its uptake by plants from the metal contaminated soil.

Table 2. Physico-chemical properties of soil

Parameters	**Values**
$pH_{1:2}$	8.1
Organic carbon %	0.44
CEC [$cmol(p^+)kg^{-1}$]	11.7
Available N (kg/ha)	227
Available P (kg/ha)	27.3
Available K (kg/ha)	350.2

Status of Heavy metal in soil

The total and available content of all selected metals in the soil before and after treatment with metal was recorded (Table 3). It was observed that both the total and available contents of metals in soil decreased after the cultivation of plants. A reason for this decrease may be due to the accumulation and uptake of metals in plant parts of crop species.

Table 3. Status of heavy metal in soil

a. Heavy metal concentration in soil before treatment

Metal	**Available (ppm)**	**Total (ppm)**
Ni	0.3	23.9
Cd	0.38	10.6
Pb	2.02	38.0
Cr	0.02	2.9

b. Heavy metal content in soil after treatment

Metal	Level 1 (ppm)		Level 2 (ppm)	
	Available	Total	Available	Total
Ni	1.32	67.61	1.48	132.3
Cd	2.21	71.67	2.34	142.4
Pb	2.45	76.4	3.34	130.3
Cr	2.01	79.5	2.2	133.6
Mixture				
Ni	0.98	60.12	1.12	121.4
Cd	1.02	63.13	1.98	128.3
Pb	1.98	69.7	2.45	121.5
Cr	1.95	69.8	1.01	124.3

Heavy metal accumulation in crop plants

Mode of heavy metal contamination

The mode of contamination was differentiated by an assumption that the metals accumulated in plants in the control pots without metal was through aerial deposition on plant parts that are above ground. Averagely, less than 10% metal accumulation in both crops were observed to be contributed via aerial deposition on plant foliage, more than 90% metal accumulation in crops was via root absorption from soil. For both crop species, the highest proportion of metal contamination via air dispersal was recorded in case of lead followed by cadmium. Among the crops, castor recorded more metal contamination through aerial deposition as compared to cotton.

Magnitude of heavy metal accumulation in plant

Metals accumulation by plants under each treatment was estimated and expressed as their concentration per unit dry weight of tissues (μg/g dry weight) in various plant parts. The results on metal contents in different plant parts are presented in (Table 4).In general, castor and cotton plants showed different pattern of metal accumulation in their different parts. In castor, maximum accumulation of metals was recorded in leaf followed by root, stem, fruit shell and least in seeds, while in cotton, highest level of metal accumulation took place in ball shell (pericarp) followed by stem, leaf, root and lowest in seeds and fibre. No marked difference amongst the content of different metals within plant species was observed, while remarkable difference in the content of different metals with respect to various plant parts between plant species was evident (Table 4).

Uptake and heavy metal partitioning into various plants parts

Different plants types have various abilities to extract metals from the soil and partition it accordingly among its different plant parts. Metal uptake was calculated by the total content of metals that was accumulated in the plant biomass per pot. Each pot contains a single plat stand. Castor that produced more biomass recorded greater metal uptake compared to cotton with less biomass (Table 5 and figure 1).

Heavy metals distribution in different plants parts

When plants absorbs metals into its system, it either stores it within the roots or being translocated into its different plant parts and this is dependent on the plant specie and the mobility of the heavy metal in question in plant. This study investigated how the selected metals are distributed in castor and cotton plant parts and results are presented in Figure 2

Table 4. Heavy metal accumulation and partitioning (μg/g dry wt.) in plants

	Castor						Cotton					
	Root	Stem	Leaf	Seed shell	Seed		Root	Stem	Leaf	Boll shell	Seed	Fibre
Ni (L1)	49.48	30.51	80.64	27.52	7.52		35.03	53.04	35.31	64.83	5.02	0.00
Ni (L2)	79.55	51.66	109.39	41.72	11.71		57.61	76.62	49.69	101.62	10.73	0.00
Mix (L1)	40.00	28.00	50.00	26.00	6.00		30.00	49.00	31.00	58.00	9.00	0.00
Mix (L2)	67.00	43.00	101.00	37.00	10.60		42.00	69.00	48.00	96.00	9.00	0.00
Control	1.10	1.20	1.30	1.02	0.00		2.30	2.30	0.00	4.30	0.15	0.00
LSDat 5%	12.98	13.44	16.67	19.41	3.45		13.67	12.67	9.41	12.65	2.71	0.00
Cr (L1)	42.48	27.96	70.34	22.53	3.80		30.01	61.30	34.15	47.88	7.90	0.00
Cr (L2)	67.5	46.6	98.09	32.53	7.81		52.70	98.12	49.14	74.19	12.36	0.00
Mix (L1)	32.00	22.00	40.00	20.00	4.67		24.00	53.00	29.00	45.00	7.50	0.00
Mix (L2)	61.00	39.00	86.00	30.00	5.60		35.00	91.00	43.00	66.00	7.50	0.00
Control	0.17	0.00	0.56	0.00	0.00		0.19	0.00	0.00	1.45	0.00	0.00
LSDat 5%	11.42	9.32	15.41	6.64	1.35		11.21	17.34	7.34	10.45	3.23	0.00

Pb (L1)	55.8	36.60	86.89	29.87	9.23		38.4	64.05	40.81	67.4	7.18	0.71
Pb (L2)	82.15	55.30	119.97	40.87	11.35		62.05	79.82	54.54	110.20	12.50	1.02
Mix (L1)	45.00	31.00	58.00	29.00	6.78		33.00	52.00	34.00	59.00	10.00	0.00
Mix (L2)	71.00	47.00	109.00	37.00	11.50		51.00	72.00	51.00	98.00	9.98	0.00
Control	0.10	1.40	7.50	2.40	0.00		0.15	1.20	2.15	2.10	1.18	0.00
LSDat 5%	12.34	6.78	13.12	5.99	1.21		12.23	15.74	7.67	9.44	2.17	0.02
Cd (L1)	35.00	25.96	71.34	20.94	7.61		25.91	46.93	36.32	40.48	7.70	0.90
Cd (L2)	50.44	44.69	109.25	27.28	9.35		47.83	73.92	49.85	98.46	13.15	1.99
Mix (L1)	27.00	20.00	57.00	18.00	5.00		20.00	42.00	30.00	41.00	7.00	0.00
Mix (L2)	49.00	35.00	104.00	24.00	10.00		30.00	65.00	47.00	89.00	6.50	0.00
Control	0.00	0.00	6.70	2.10	0.00		0.00	0.00	1.00	0.00	0.00	0.00
LSD at 5%	12.56	7.12	12.45	5.67	1.21		11.23	16.67	6.78	8.34	2.12	0.04

L1=50ppm, L2=100ppm, Mix=Ni+Cr+Pb+Cd

Table 5. Uptake and partitioning of heavy metal in various plants parts(mg/pot dry wt.)

	Castor							**Cotton**						
	Root	**stem**	**leaf**	**seed shell**	**seed**	**Total**		**Root**	**stem**	**leaf**	**boll shell**	**seed**	**fibre**	**Total**
Ni (L1)	0.99	11.29	2.82	1.07	0.56	**16.74**		0.70	7.96	1.06	2.27	0.14	0.00	**12.13**
Ni (L2)	1.83	11.88	3.61	1.54	0.84	**19.71**		1.27	11.65	1.59	3.35	0.25	0.00	**18.10**
Mix (L1)	0.88	4.06	1.70	0.79	0.35	**7.77**		0.63	6.76	0.87	1.22	0.07	0.00	**9.55**
Mix (L2)	1.54	6.88	3.64	0.70	0.35	**13.11**		0.97	9.04	1.39	2.02	0.06	0.00	**13.48**
Control	0.06	0.81	0.09	0.04	0.00	**1.00**		0.05	0.32	0.00	0.12	0.00	0.00	**0.48**
LSDat 5%	0.23	2.11	1.02	0.07	0.09			0.41	0.55	0.10	0.11	0.09	0.00	
Cr (L1)	0.68	5.54	2.81	0.77	0.25	**10.05**		0.66	9.87	1.02	1.53	0.15	0.00	**13.24**
Cr (L2)	1.35	9.83	3.43	0.98	0.48	**16.07**		1.26	14.82	1.43	2.15	0.21	0.00	**19.87**
Mix (L1)	0.70	3.19	1.36	0.60	0.27	**6.13**		0.50	7.31	0.81	0.95	0.06	0.00	**9.64**
Mix (L2)	1.40	6.24	3.10	0.57	0.18	**11.49**		0.81	11.92	1.25	1.39	0.05	0.00	**15.41**
Control	0.00	0.00	0.02	0.00	0.00	**0.03**		0.00	0.00	0.00	0.07	0.00	0.00	**0.07**
LSDat 5%	0.18	2.13	1.09	0.06	0.07			0.81	0.62	0.17	0.12	0.05	0.00	
Pb (L1)	1.00	6.95	3.04	1.25	0.76	**13.01**		0.88	9.93	1.35	1.48	0.07	0.01	**13.72**
Pb (L2)	1.56	11.72	4.56	1.02	0.55	**19.41**		1.37	11.09	1.75	2.53	0.13	0.01	**16.88**
Mix (L1)	0.99	4.50	1.97	0.88	0.39	**8.72**		0.69	7.18	0.95	1.24	0.08	0.00	**10.14**
Mix (L2)	1.63	7.52	3.92	0.70	0.38	**14.16**		1.17	9.43	1.48	2.06	0.07	0.00	**14.21**
Control	0.00	0.52	0.28	0.10	0.00	**0.90**		0.00	0.16	0.07	0.06	0.03	0.00	**0.33**
LSDat 5%	0.17	3.12	1.67	0.10	0.09			0.67	0.79	0.19	0.18	0.09	0.00	
Cd (L1)	0.81	6.62	2.71	0.59	0.42	**11.14**		0.57	6.38	1.13	0.89	0.07	0.01	**9.05**
Cd (L2)	1.16	8.49	4.15	0.55	0.35	**14.70**		1.10	11.16	1.60	2.26	0.12	0.03	**16.27**
Mix (L1)	0.62	3.20	2.05	0.34	0.17	**6.38**		0.46	5.50	0.87	0.86	0.05	0.00	**7.74**
Mix (L2)	1.32	5.60	3.85	0.97	0.72	**12.46**		0.63	8.91	1.60	2.40	0.19	0.00	**13.72**
Control	0.00	0.00	0.25	0.08	0.00	**0.33**		0.00	0.00	0.03	0.00	0.00	0.00	**0.03**
LSDat 5%	0.19	2.98	1.12	1.11	0.13			0.46	0.67	0.13	0.12	0.09	0.00	

L1=50ppm, L2=100ppm, Mix=Ni+Cr+Pb+C

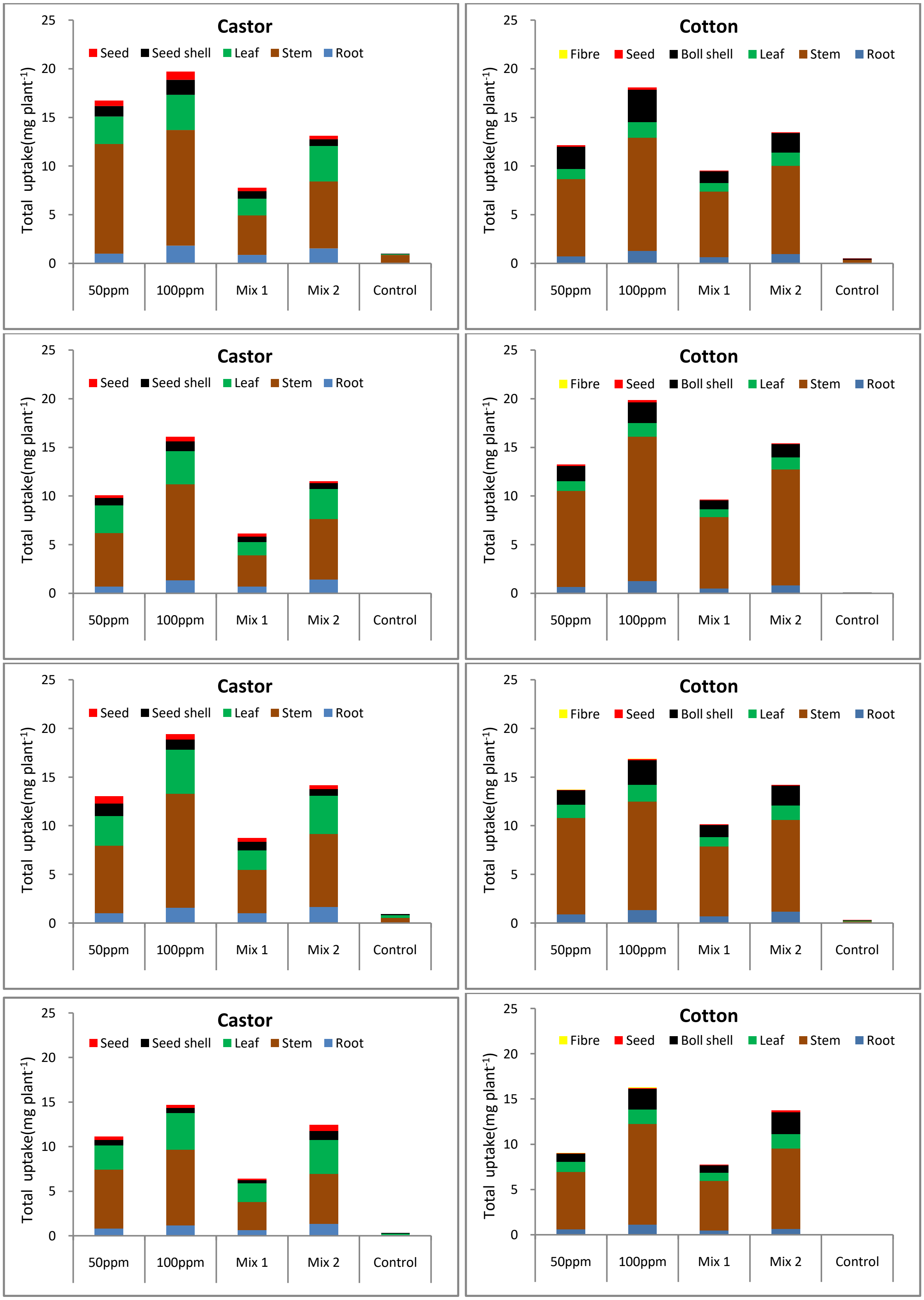

Fig. 1. Uptake and partitioning of heavy metals in various plants parts.

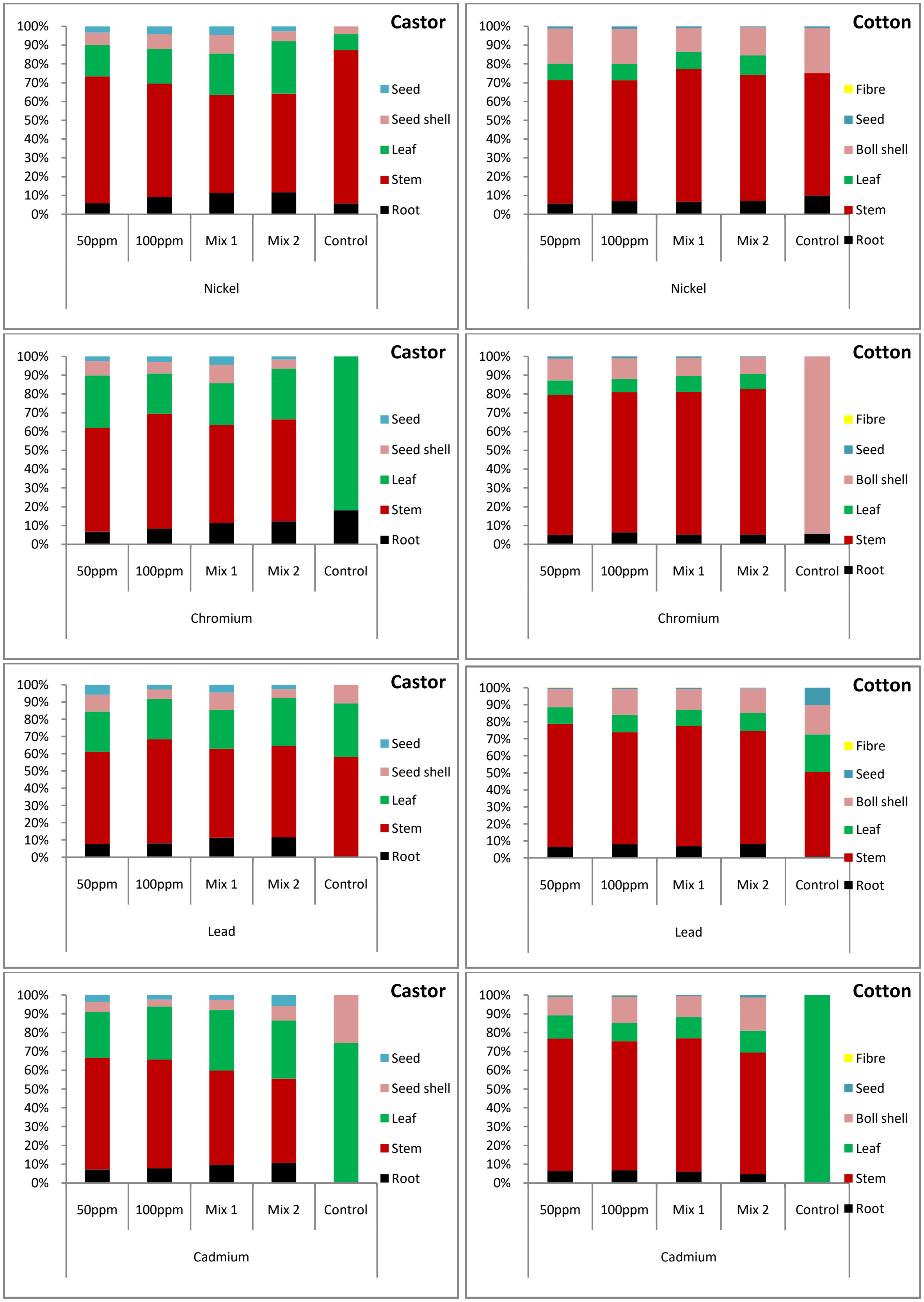

Fig. 2.Heavy metal distribution pattern in different plants parts (%).

IV. DISCUSSION

Mode of metal uptake

Plants accumulate metals into their tissues by absorbing them from contaminated soils, also from possible aerial depositions on different parts that are exposed to the air from polluted environment. Rainfall and all other forms of precipitations and also dusts are able to deposit atmospheric metals on plant surfaces. It can be concluded from this research that aerial metal deposition contributes minor part from total accumulation of metals by both plants as they were grown on metal emended soils. Soil as the major source contributed more than 90% to total accumulated heavy metals in plant tissues. Castor was observed to have more share of aerial contamination than cotton. This may be probably due to the larger canopy coverage and wider leaves of castor even though the wider leaves surfaces are smooth which may possibly have reduced the adherence of the deposited metals and thereby reduced absorption. more proportion of aerial metal contamination was recorded in Pb and then Cd, this possibly may be because there was a power generating plant located near the experimental station. Sharma *et al*. 2008 has reported an increased contamination by lead and cadmium around urban areas due to traffics.

Metal accumulation in plants parts

Studies by Mohamed *et al.* 2003 reported that different plant species has varying capacities to selectively bio-accumulatemetals. Both crop species under the present investigation have shown some variations in regards to accumulation of heavy metal in their tissues. Metal content Analysis in both crops that were grown in different metals and treatments with combined metals treatment shows that different crop species accumulates different heavy metals at different concentration levels in different plant parts.

Stem was seen as the major part for metal accumulation in both crops. Although Cheng and Huang, 2006 reported that roots of most crops accumulates more heavy metal concentration than other plant parts. Diwan*et al*. in 2012 suggested from the observations from his work that as plants gets older, their ability of to transfer metals into above ground vegetation from its roots also increases, and this may be the reason why there was higher accumulation in stems and other above ground parts recorded under the present study. Cotton was seen to accumulate more Chromium and Cadmium than castor in its tissues. Similar observations was also reported by Ni *et al*. in 2002 indicating that the concentration of cadmium in plant parts varies type of plant and the concentration level of cadmium.. In general this study has revealed a trend of metal accumulation to different plant part with castor showing its accumulation trend as Stem>Leaf>Root>Seedshell>Seed; while in cotton it followed the order Stem>bollshell>Leaves>Root>Seed>fibre.

Heavy metals accumulation by plant is largely dependent on several factors such as plant species and its root system, environment i.e pH, temperature, organic content e.t.c and the metals itself in terms of availability in soil medium, mobility and chances of aerial deposition reported by Singh and Kumar, 2006; Nagajyoti*et al.*, 2010. Heavy metal accumulation in bothe crops in this tresent study followed the order: Pb>Ni>Cr>Cd. These observed pattern of lead accumulation which was followed by nickel, the chromium and lastly cadmium for both crop species are in agreement with what has been reported by several researchers (Barman and Lal, 1994; Singh and Aggarwal, 2006; Singh *et al*., 2012; Kumar *et al*., 2014).

As the concentration heavy metal in soil increases, the accumulation also proportionately increased. This correspondence in metal accumulation increasing with increasing metal content in soil was reported by Jiang *et al*. in 2004 in their studies of Cd in mustard . Mixture of metals in a combined treatment was found to record a reduced accumulation of heavy metals for both crops compared to single metal application irrespective of metals It has been reported in 1996 by John and Leventhal through their works that bio availability of metals can be related to other metals that are present and their ratios in soil and also how they interact may either result to effects which can be stimulatory or antagonistic (Luoma, 1977). The same study reported Cd uptake stimulated by Pb, and an antagonism between Copper and lead; and Cadmium and Mercury.

Metal uptake by plants

Brooks and Robinson, (1998) reported plants that produces hiher biomass and a moderate concentrations of heavy metals are in some cases more effective to remove heavy metals that plants that produces lower biomass and accumulates metals in high concentrations. In this present study, even though cotton shows a little bit higher concentrations of lead and nickel in its tissues, Castor recorded a higher uptake of both metals than cotton from soil. This might be as a result of the different in biomass as castor produces more biomass compared to cotton.. Cotton was seen to be a hyper- accumulator of Chromium and Cadmium by recording higher accumulation and uptake for both metals. Shiyab*et al*. (2009) in his works has described mustard as a hyper-accumulator because of its faster growth and high biomass production.

Distribution of heavy metals to different plant parts

This study partly aimed to investigate the distribution patterns of different metals to different parts of castor and cotton. Several researchers have reported partitioning of metals into various plant parts of different crop species. Singh *et al*., 2012 reported that spinach accumulated more heavy metal in its leaves than what was accumulated in the root and contrarily Rangnekar*et al*., 2013 reported more distribution of metals in roots. Alcantara*et al*. (2001) discovered higher partitioning of heavy metals into its leaves and lower into seeds by beans, melon, pea tomato, pepper and. This present study shows that castor and cotton distributed greater portions of metals into its stems and leaves compared to what was partitioned into the roots of both plants. It was also observed in the present finding that both crops accumulated greater proportions of metals into its vegetative parts rather than in its reproductive parts which is in conformity with the observations of other some other scientists (Allinson and Dzialo, 1981; Iretskeya and Chien, 1998; Kim *et al*., 2002) who reported that metals were accumulated into vegetative parts rather than in the edible parts of some selected crops. This could be attributed to poor mobility of the heavy metals within the plant system.

V. SUMMARY AND CONCLUSION

The ecosystem pollution has reached an alarming state due to various anthropogenic activities in order to improve the lifestyle and meet the rising food demand. The agro-ecosystem which meets the demand of the growing population in terms of food and other raw materials is now under threat and pollution by heavy metals is contributing a share that cannot be ignored. Soil is a major factor for agricultural productivity and it serves as an ultimate sink for these heavy metals. Change in its quality status will lead to severe detrimental effects. Agriculture and industrial wastes has resulted into increased accumulation of heavy metals in soils along with other sources such as automobiles and power plants. Metals have a long residence time and can move from soil to plants thereby contaminating the food chain and they cannot be easily removed once they find their way into the soil-plant-animal continuum. The metals have various adverse effects on both plant and animal health. Plant in general shows different accumulation and distribution capacities depending on plant species, type of metal and plant characteristics etc. Several attempts has been made by several researchers for environmental clean up by plants , however selection of crops to be grown on metal contaminated soil is very important on the basis of heavy metal accumulation in the edible parts so as not to defeat the purpose of heavy metal removal from the environment by consuming such crops. The present study was undertaken in order to investigate the mode and magnitude of four heavy metals viz; Nickel, Chromium, Lead and Cadmium contamination so as to understand their accumulation and distribution in two non-edible, commercial and industrial crops i.e Castor and Cotton The findings of the present investigation carried out during the kharif season 2015 (April to October 2015) are summarised as under.

- No phototoxic symptoms were observed in any crop throughout their growth period.
- Metal accumulation in both crops followed the order Pb>Ni>Cr>Cd
- Heavy metal accumulation was found to increase proportionately as the concentration of metals in soil increased.
- Combination treatments showed significant reduction in all metal accumulation in both crops when compared with the application of a single metal.
- Aerial deposition contributed < 10% to total metal accumulation while > 90% of the metal accumulation was recorded through root absorption.
- Metal aerial deposition was higher on castor than on cotton.
- Maximum aerial deposition was recorded in Pb followed by Cd, while no evidence of aerial deposition was observed in Ni and Cr.
- Metal uptake was crop specific whereby Ni and Pb uptake was higher in castor while Cr and Cd were higher in cotton.
- Metal distribution in Castor plant parts followed the order Stem>Leaf>Root>Seedshell>Seed; while in cotton it followed the order boll shell>stem>Leaves>Root>Seed>fibre.
- Aerial deposition contributes less heavy metal contamination in plants compared to root uptake
- Distribution of almost all the metals was found to be maximum in vegetative parts compared with reproductive parts.
- Within the reproductive parts (seed shell and bolls hells) recorded maximum distribution as compared to economic parts (seed and fibre).
- Both plants seemed to be hyper-accumulators and found almost at par in respect of heavy metal extraction/removal from metal contaminated soils.

From the study it could be concluded that, both plants are able to extract/remove metals from the soil in significant quantities. From environment clean-up point of view, castor and cotton are both suitable for Phyto-remediation of heavy metal polluted soil and this will help reduced surface water pollution which may result from run-offs from polluted soil and also groundwater pollution due to leaching of these heavy metals making it suitable for aquaculture purposes.Castor is recommended where Ni and Pb are dominant pollutants while Cotton in case of Cr and Cd.In view of health and safety, castor seeds can be used safely with caution due to its low metal accumulation traits.Heavy metal accumulated in cotton fibre was mainly due to aerial deposition- hence it could be grown in metal contaminated soils. However, caution and due diligence should be ensured when disposing off the metal contaminated vegetative biomass.

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