Relative Efficiency of Different Crops for their Phyto-extraction Capacity in Managing Heavy Metals Stress

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Abstract

A study was undertaken to study the different plant species for their heavy metals removal capacity and suitability for phytoremediation under micro plots (1.5×1.0×0.5 m^3) at Anand Agricultural University using factorial completely randomized design with three replications. The soil in bulk having sandy loam texture was collected from mixed industrial effluent irrigated fields and adjoining tube well irrigate fields and utilized in the micro plots. Three levels of irrigation water viz., 100% mixed industrial effluent, 1:1 diluted effluent and tube well water were kept to study their effect on growth and yield of different crops sunflower, cotton, tobacco and castor. Among the crops, the biomass yield of castor was maximum followed by cotton, while minimum yield was recorded in tobacco. The overall findings of the present study indicated that the castor could remove more quantity of total heavy metals (Cd+Ni+Cr+Co+Pb) from contaminated soil in one cropping season than other crops viz., cotton, tobacco and sunflower. However, the extraction efficiency of tobacco for total heavy metals was higher than the other crops for production of unit biomass unit $time^{-1}$; and followed the ascending order tobacco>sunflower>cotton>castor. The values of accumulation factors confirmed the order of phytoextraction efficiency of the crops. Therefore, the suitable crop needs to be selected for bioremediation of contaminated site depending on the factors like availability of time and economic importance of the crop.

1. Introduction

The rapid industrial development in Gujarat has caused several problems of soil-water pollution due to the indiscriminate disposal of industrial effluents on agricultural lands. It is becoming a major source of heavy metals stress in irrigated soil and ultimately in ground water. The unwise use of such contaminated water for irrigation purpose has elevated levels of available heavy metals in the cultivated layer of the soil (Adhikari et al., 1993).

The metals stress often cited as a problem is cadmium, chromium, lead and arsenic (Forstner, 1995). The threat that heavy metals stress pose to human and animal health is aggravated by their long-term persistence in environment is quite relevant in the present scenario due to its deleterious effect on animals-human health via food chain. The heavy metals accumulating in soil may get entry into the human and animal food chain through the crops like leafy vegetables and tuber crops which are grown on it (Haan and Lubbers, 1985). Therefore, the heavy metals contaminated fields need appropriate management by using cost effective and environmentally friendly emerging technology to eliminate or minimize the health hazards. Hardly any information is available on such aspect for contaminated soils of Gujarat. Keeping this in view, the present study was therefore undertaken to study the different plant species of local importance for their heavy metals removal capacity and suitability for phytoremediation.

2. Materials and Methods

The experiment was conducted in cemented (1.5×1.0×0.5 m^3) micro plots in the experimental yard of the Micronutrient Project (ICAR), Anand Agricultural University, Anand, Gujarat state, India, during 2005-06. The bulk soil samples were collected from mixed industrial effluent irrigated fields (contaminated soil) and from tube-well water irrigated fields (non-contaminated soil) of the same area (Ahmadabad) for micro plot study. The soil was air dried and ground to pass through 8 mm sieve. After thorough mixing, the contaminated soil (S_1) was filled into 36 cemented micro plots and in another set of 36 micro plots, non-contaminated soil (S_2) was filled up to 50 cm depth from the top. The basal dose of fertilizers to each of the crops was given at the time of sowing. The others agronomical practices as per required were followed. Four healthy plants were kept in each micro plot at the approximate 80×20 cm spacing. The known quantity of irrigation was given as and when required as per the treatments. Three levels of irrigation water viz., 100% mixed industrial effluent (I_1), 1:1 diluted effluent (I_2) and tube well water (I_3) were kept to study their effect on growth and yield of different crops [Sunflower(SF) (*Helianthus annus,* cv. GS-1), Cotton (CT) (*Gossypium hirsutum,* cv. GCH-8), Tobacco (TB) (*Nicotina tabacum,* cv. GTH-1) and Castor (CS) (*Ricinus communis,* cv. GSH-5).The crops were grown up to maturity and necessary observations were recorded. The experiment was conducted under factorial completely randomized design keeping three repeats. Treatment combinations was twenty four (2 Soils* 3 Irrigations* 4 Crops). The initial soil samples were collected, the soil was air dried and ground to pass through 2 mm stainless sieve and the important soil physical property i.e., soil texture was estimated by mechanical analysis for separates (sand, silt and clay) using International Standard Pipette Method (Piper (1966). The chemical properties i.e. pH, EC (1:2.5 soil:water ratio), organic carbon (OC), available PK method outlined by Jackson (1973), Available S (Williams and Steinbergs (1958), beside DTPA (Diethylene Triamine Penta Acetic Acid)-extractable as well as total heavy metals as explained by Lind say and Norvell (1978) and Tessier et al. (1979), respectively. The results are presented in Table 1. Plant samples of all parts of the plant for each crop at harvest of the crops were collected and processed after proper washing, air and oven drying at 70°C were subjected to di-acid digestion (HNO_4+$HClO_4$, 4:1) to determine the concentration of heavy metals using Atomic Absorption Spectrophotometer. The values of accumulation factors (AF) for all the heavy metals were calculated by using the formula: AF=Mean plant concentration (Total content) mg kg^{-1}÷Mean soil available (mg kg^{-1}) concentration outlined by Nirmal Kumar et al. (2008). The statistical analysis was done as per the methods suggested by Steel and Torrie (1982).

Table 1: Physical and chemical characteristics of initial soil

Sl. No.	Parameter and method	Value	
		Contaminated Soil (S_1)	Non-contaminated Soil (S_2)
1.	Mechanical analysis (International pipette method):		
	Coarse sand (%)	2.8	11.5
	Fine sand (%)	53.9	54.5
	Silt (%)	27.4	26.2
	Clay (%)	15.4	07.5
2.	Texture and classification	Sandy loam	Sandy loam
3.	pH	8.4	7.72
4.	Electrical Conductivity (dSm^{-1})	0.25	0.14
5.	Organic carbon (%)	0.64	0.62
6.	Avg. P_2O_5 (kg ha^{-1})	102.00	101.00
7.	Avg. K_2O (kg ha^{-1})	332.50	221.70
8.	Avg. S (0.15% $CaCl_2$) (mg kg^{-1})	10.24	7.24
9.	DTPA-extractable cations heavy metals (mg kg^{-1})		
	Cd	0.12	0.06
	Ni	0.42	0.47
	Cr	0.04	0.02
	Co	0.22	0.20
	Pb	1.74	1.18
10.	Total metals heavy metals (mg kg^{-1})		
	Cd	4.5	3.0
	Ni	44.2	37.5
	Cr	125.0	96.0
	Co	17.5	15.0
	Pb	72.5	59.0

3. Result and Discussion

3.1. Growth and crops yield

The total biomass yield was significantly influenced by the crop and irrigation factors while soil factor was non-significant. Among the crops, the total biomass yield of castor was significantly higher (19.449 kg $plot^{-1}$) followed by cotton (2.335 kg $plot^{-1}$) while minimum yield was recorded in tobacco (0.849 kg $plot^{-1}$). The effect of irrigation water indicated that yield of castor under effluent irrigation was significantly higher (6.331 kg $plot^{-1}$) than tube well irrigation (5.679 kg $plot^{-1}$) being at par with 1:1 dilution (Table 2) due to waste water is an important source of plant nutrients and helps in improving the crops yields. The effect of C×I and S×C×I interactions were also found significant (Table 2).

3.2. Removal of heavy metals by crops

The heavy metals uptake for individual element and sum of the heavy metals (Cd+Ni+Cr+Co+Pb) was computed in order to know the heavy metals removal capability of the crops in a season.Theresults are graphically presented in Figure 1 and 2 under soil condition and irrigation water condition respectively for total heavy metals. The results are clearly revealed that the total uptake of total heavy metals was remarkably higher in castor; while the other crops behaved almost in a similar way so far as the heavy metals removal from the soil was concerned. Obviously the higher biomass yield of castor depicted higher removal of total heavy metals which was almost about 10 times higher than other crops except cotton; while sunflower and tobacco were almost equally effective in this respect (Figure 1).

Further the results revealed that the removal of total heavy metals was comparatively higher under contaminated soil condition than non-contaminated soil (Figure 2). Similarly, the removal of the total metals was comparatively higher under effluent irrigation than diluted effluent and tube well water irrigation as shown in Figure 2. The similar results were also made by Rio et al. (2000), Shu-Wensheng et al. (2004), Shahandeh and Hossuer (2000) The mechanism of plants varies with species as reported by Felix (1997), he noticed that certain wild plants as well as crop plants were able to accumulate large amounts of heavy metals in their above ground parts. Similarly, Tsakou et al. (2001) also reported accumulation of trace and heavy metals (Zn, Fe, Mn, Cr, Ni, Cu and Pb) in cotton (*Gossypium hirsutum* Cv. Zetaz) but no toxic effect was observed on the plants.

3.3. Total heavy metals removal efficiency of different crops

The different crops have produced variable total biomass and also crop duration was different among the crops; therefore, the efficiency of different crops for their heavy metals extraction capacity was evaluated by computing total removal of all heavy metals *viz.*, Cd+Ni+Cr+Co+Pb kg^{-1} of biomass production micro $plot^{-1}$ as well as unit $time^{-1}$. The data on total heavy metals removal by the crops as influenced by different soil conditions are graphically presented in Figure 3 and 4.

3.3.1. Soil condition

It was clearly noticed that tobacco could extract maximum heavy metals for production of 1 kg of biomass in a given plot area (size=1.0×1.5 m^2) under both the soil conditions compared to other crops. The maximum removal of 47.3 mg kg^{-1} $plot^{-1}$ was recorded in contaminated soil followed by 41 mg kg^{-1} $plot^{-1}$ in non-contaminated soil by the tobacco (Figure 3). The heavy metals extraction capacity of sunflower was nearly 60% of the tobacco while similar capacity of cotton and castor was by about 50 and 40% of tobacco, respectively under both the soil conditions.

The further computation of total heavy metals removal based on unit biomass production unit $time^{-1}$ (mg kg^{-1} day^{-1} $plot^{-1}$) for different crops has been presented in Figure 4. The duration of all the crops varied from 120 day in sunflower to maximum 250 days in cotton, therefore, the phyto-extraction capacity also varied on time scale basis. The results clearly indicated that although, the absolute removal of total heavy metals unit biomass $production^{-1}$ was maximum in tobacco, its capacity unit $time^{-1}$ basis was almost similar to that of sunflower. Both the crops could remove about 0.2 to 0.25 mg kg^{-1} day^{-1} of total heavy metals under different soil conditions. The extraction capacity of tobacco was comparatively higher under contaminated soil condition than non-contaminated soil, while sunflower showed somewhat reverse trend in this aspect. It was also interesting to note that castor and cotton both the crops were found equally effective in removal of total heavy metals kg^{-1} of biomass production unit $time^{-1}$ of crop duration. In general, the total heavy metals removal was significantly higher under contaminated soil than non-contaminated soil in all the crops except sunflower.

3.3.2. Irrigation water

The total heavy metals removal data by different crops as

Table 2: Effect of different irrigation water on yield of total biomass of crops under different soil conditions

Soil (S) and Crops (C)		Total biomass (g $plot^{-1}$)			
		Irrigation water (I)			
		I_1	I_2 (1:1)	I_3 (TW)	Mean (S×C)
S_1	SF	1753	1234	1102	1363
	CT	2271	2018	2778	2356
	TB	679	869	930	826
	CS	21929	20055	17091	19692
Mean (S×I)		6658	6044	5475	6059 (S_1)
S_2	SF	1241	1578	1345	1388
	CT	2370	2015	2497	2294
	TB	989	926	703	873
	CS	19420	19212	18986	19206
Mean (S×I)		6005	5933	5883	5940 (S_2)
Mean (I)		6331	5988	5679	
		Mean (C×I)			Mean (C)
Crop (C)	SF	1497	1406	1224	1376
	CT	2321	2016	2638	2325
	TB	834	898	817	849
	CS	20675	19633	18039	19449

	S	C	I	S×C	S×I	C×I	S×C×I
SEm±	A	B	C	D	E	F	G
CD (p=0.05)	NS	537	465	NS	NS	929	1314

A=133.45; B=188.73; C=163.44; D=266.90; E=231.14; F=326.88; G=462.28; I: Effluent

Sunflower (SF) (*Helianthus annus*, cv. GS-1); Cotton (CT) (*Gossypium hirsutum*; cv. GCH-8); Tobacco (TB) (*Nicotina tabacum*; cv. GTH-1) and Castor (CS) (*Ricinus communis*; cv. GSH-5); S_1: Contaminated; S_2: Non-contaminated

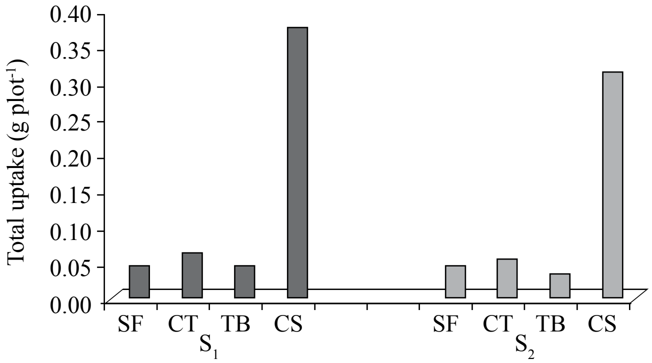

Figure 1: Total heavy metals (Cd+Ni+Cr+Co+Pb) uptake by the crops under different soil conditions.

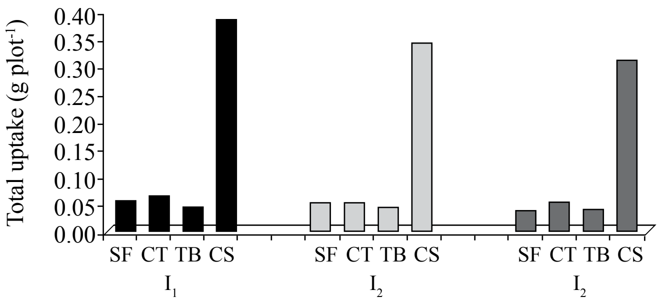

Figure 2: Total heavy metals (Cd+Ni+Cr+Co+Pb) uptake by the crops with different irrigation water.

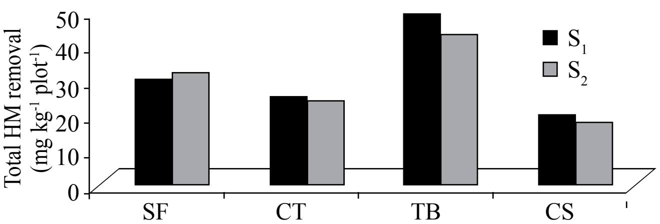

Figure 3: Total heavy metals (Cd+Ni+Cr+Co+Pb) removal efficiency of the crops under different soil conditions.

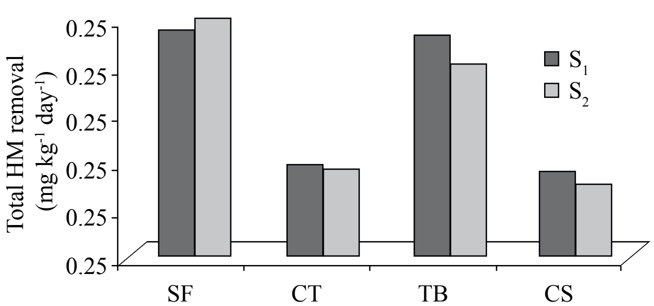

Figure 4: Total heavy metals (Cd+Ni+Cr+Co+Pb) removal efficiency of the crops under different soil conditions.

influenced by different quality of irrigation water are presented for production of one kg biomass and also unit time^{-1} in Figure 5 to 6, respectively. The results clearly revealed that total heavy metals extraction capacity of tobacco was much higher than other crops for production of unit biomass weight plot area^{-1}

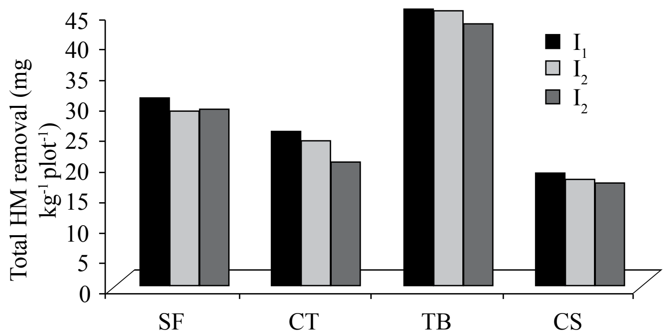

Figure 5: Total heavy metals (Cd+ Ni+Cr+Co+Pb) removal efficiency of the crops with different irrigation water.

due to different quality of irrigation water.

In general, the phyto-extraction capacity of different crops for heavy metals was in the order of tobacco>sunflower>cotton> castor under different irrigation water; and it was comparatively higher under effluent irrigation than tube well water in all the crops. Further, it was revealed that the total heavy metals extraction capacity for production of unit biomass unit time^{-1} (mg kg^{-1} day^{-1}) was found almost similar in cotton, tobacco and sunflower, although the total extraction unit biomass production^{-1} was more in tobacco than sunflower. Similarly, the phyto-extraction capacity of cotton and castor for total heavy metals to produced unit biomass unit time^{-1} was almost equal under different quality of irrigation. The higher removal under effluent irrigation was due to obvious reason as more of the heavy metals were introduced through effluent irrigation compared to tube well water irrigation. The overall results indicated that the phyto-extraction capacity of heavy metals for production of unit biomass unit time^{-1} was almost equal for sunflower and tobacco in one group; and cotton and castor in other group. The results are also in accordance with those reported by Keller et al. (2003) and Wenger et al. (2002)

3.4. Accumulation factor

The efficiency of different crops to accumulate heavy metals under different soil conditions and quality of irrigation water was assessed by computing accumulation factors. The maximum value of accumulation factor was cited with tobacco, while minimum was noted with castor for all the elements except Ni (Table 3). Thus, the values compared for accumulation factors supported the variable efficiency of different crops in removal of heavy metals from the soil. In general, it was noticed that the tobacco showed the heavy metals removal efficiency greater than all other crops followed by castor and cotton on the basis of unit biomass production unit time^{-1} (Figure 3 to 6). Kumar et al. (2008) reported similar findings of accumulation factors for twenty selected vegetable crop of whole plants.

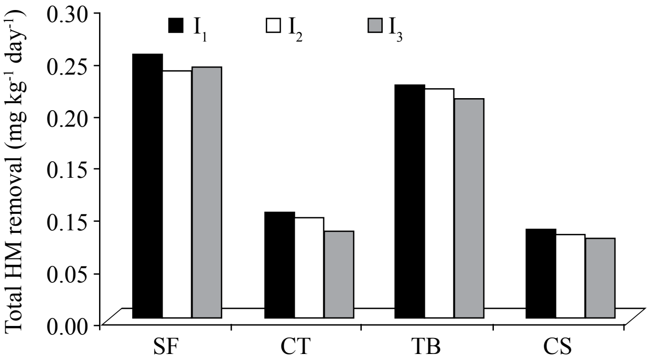

Figure 6: Total heavy metals (Cd+Ni+Cr+Co+Pb) removal efficiency of the crops with different irrigation water

Table 3: Accumulation factor of heavy metals for different crops as affected by quality of irrigation water and soil conditions (overall conditions)

Cd: CS (12)	<	CT (12)	<	SF (20)	<	TB (35)
Ni: CT (7)	<	CS (9)	<	SF (12)	<	TB (14)
Cr: CS (95)	<	CT (191)	<	SF (341)	<	TB (359)
Co: CS (10)	<	SF (16)	<	CT (17)	<	TB (20)
Pb: CS (4)	<	CT (6)	<	SF (6)	<	TB (10)

4. Conclusion

Among the crops, the biomass yield of castor was maximum followed by cotton; while minimum yield was recorded in tobacco. The castor could remove more quantity of total heavy metals (Cd+Ni+Cr+Co+Pb) from contaminated soil in one cropping season than other crops viz., cotton, tobacco and sunflower. However, the extraction efficiency of tobacco for total heavy metals was higher than the other crops for production of unit biomass unit time^{-1}; and followed the ascending order tobacco>sunflower>cotton>castor. The same was further confirmed by higher accumulation factors values in tobacco and minimum with castor. Therefore, the suitable crop needs to be selected for bioremediation of contaminated site depending on the factors like availability of time and economic importance of the crop.

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