Comparative Evaluation of Phytoremediation Potential of Indian Mustard (*Brassica juncea*) Varieties Under Sewage Irrigated Sites

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Long-term application of sewage for crop production accumulates significant amount of heavy metals in soil. Some of these metals are carcinogenic and affect the soil, plant, animal and human health adversely. Phytoremediation with mustard is a well known and regularly adopted practice for metal removal from contaminated areas. However, genetic potential of mustard cultivars may have much influence on phytoremediation potential of mustard. For this, four prominent mustard crop varieties (NRC DR 2, NRC HB 101, RH 749 and RH 119) were grown at sewage contributed metal contaminated agriculture fields of Islamnagar and Bheropura villages. Results showed that all the mustard varieties removed significant amount of Cu, Cd, Pb, Cr, Ni, Zn and Mn from soil. Mean data of all three locations showed that maximum removal of Cu (479 mg plant^{-1}), Cd (2.80 mg plant^{-1}), Cr (38.1 mg plant^{-1}), Ni (9.96 mg plant^{-1}), Zn (26.6 mg plant^{-1}) and Mn (538 mg plant^{-1}) was in NRC HB 101 except for Pb uptake which was highest in NRC DR 2 (1.53 mg plant^{-1}). The NRC HB 101 showed higher phytoextraction potential compared to rest of the varieties. These results are very much useful for formulation of phytoremediation management strategies under metal contaminated agriculture areas.

Key words: Crop uptake, heavy metal, mustard cultivar, phytoremediation, soil health

Rising heavy metals pollution in agricultural ecosystem has become a serious concern worldwide (Saha *et al.* 2017). These metals persist in nature for long time and happen to be toxic in plants, animals and humans when these surpass specific threshold concentration levels. Metal contamination in agricultural fields are due to anthropogenic activities like industrial waste disposal, faulty agriculture management practices, use of municipal solid waste and industrial effluents, *etc*. Sewage irrigation for crop production is an alternative practice to meet water requirement of the crops particularly in peri-urban areas (Dotaniya *et al.* 2018a). Sewage water contains heavy loads of organic matter, nutrient elements, heavy metals and other contaminants. Long- term utilization of sewage can lead to accumulation trace metals in the soil that become toxic to plant, animal and human health (Dotaniya *et al.* 2018a). Therefore, removal of metals from contaminated sites is inevitable for sustaining crop production. Although, there are many approaches followed to remediate contaminated sites, phytoremediation is considered farmers-friendly, cost effective, non destructive and eco-friendly plant based approach for metal remediation (Van Ginneken *et al.* 2007; Ali *et al.* 2013; Meena *et al.* 2020).

Phytoremediation is a method of bioremediation for removal of pollutants from any natural system (soil, air and water) using different kinds of living plants. The processes involved are removal, transfer, stabilization, and/or destruction of contaminants in soil and water. Phytoremediation can be applied in polluted soil and water environment for removal of heavy metal contaminants under variable soil and climatic conditions (Dotaniya *et al.* 2020). This method is highly recommended as it usually does not have negative effect on the health of environment including soil ecosystem.

Phytosequestration or phytoextraction processes are more popular across the globe since the last 20-30

years (Grispen *et al.* 2006). The plants generally used for this purpose are called hyper accumulators. There is wide variability among plant species regarding accumulation of heavy metals from contaminated ecosystem. On the basis of different metal accumulation indices plants are categorized as low, medium and hyper accumulators. Mustard plants, alpine pennycress, hemp, and pigweed were identified as a hyper accumulator for remediation of metal from toxic waste sites (Rascio and Navari-Izzo 2011). Interestingly Indian mustard (*Brassica juncea*) was observed to serve as an efficient phytoremediator of some heavy metals (Rathore *et al.* 2019). Mustard plants have been widely used for removal of contamination particularly heavy metals from polluted sites (Rathore *et al.* 2019). Though there are many challenges, effective removal of metals by adoption of agronomic management practices had enhanced ability of crops to absorb and uptake of plant nutrient and concentrate heavy metals from contaminated soils (Rathore *et al.* 2019; Meena *et al.* 2020).

Though there are many studies on heavy metal remediation using mustard species, an efficient cultivated variety of mustard for use as phytoextracter of heavy metals under lowly contaminated soils has not been identified. In the current study, metal uptake potential of four Indian mustard cultivars is investigated under farmers' field condition in lands contaminated through long-term sewage water irrigation.

Material and Methods

Field locations

The field experiment was conducted in sewage irrigated areas near Bhopal city, India. Patranala (sewage carrying natural channel), is the major source of irrigation water in several surrounding villages. On the basis of survey on intensity of sewage utilization for crop cultivation, two experiments at Islamnagar village and one experiment at Bheropura village were conducted. Both the villages are having near proximity with Bhopal (about 15 km), the capital city of Madhya Pradesh.

Collection of soil and sewage

Geo-referenced sewage and soil samples were collected from three experimental locations prior to conduct the field experiments. Collected sewage samples were acidified with dilute acid for controlling microbial growth and for preventing heavy metal precipitation during storage. Another set of sewage samples were collected for other chemical parameters analysis. Surface soil (0-15 cm) samples were also collected from these locations demarcated for field experiments. Each sample was assigned unique identity number, processed and kept for further laboratory analysis.

Initial soil and sewage analysis

Soil physicochemical parameters were analyzed following the methods described in Jackson (1973) and the results are described in table 2. Collected sewage samplers were digested with di-acid mixture. For this 100 mL sewage water taken into conical flask and 5 mL of HNO_3 was added and kept for pre-digestion. After 2-3 h, 10 mL di-acid (HNO_3 and $HClO_4$ in 9:4 ratio) was added and digested on hot plates till the white fumes appeared. Then 50 mL of double distilled water was added and filtered, for heavy metals analysis. Similarly for soil analysis, 0.5 g sample was digested using di-acid mixture and the extractant was prepared. The DTPA extractable metal content was measured as per the method described by Lindsay and Norvell (1978). Metal contents in digested and/or extracted sewage and soil samples were measured with the help of inductively coupled plasma optical emission spectroscopy (ICP-OES) (Perkin Elmer Precisely Optima 2100 DV) for heavy metals.

Field experiment

Fields were prepared with one deep plough and two shallow ploughs to homogenize the root zone and mustard varieties were sown manually at 15 cm plant to plant and 45 cm row to row distance. Fertilizers were applied as per recommended doses (80:40:40 kg ha^{-1} N: P_2O_5: K_2O, respectively) using urea, single super phosphate (SSP) and muriate of potash (MOP) sources. Five irrigations were applied during the crop period. Crop was raised in all the three locations following similar agronomic management practices. Crop varieties were harvested at full vegetative stage and were dried in oven at 70±2 °C. After drying samples were pulverized and kept for metal analysis in air tight plastic bags.

Mustard varieties and their characteristics

In the investigation, the phytoremediation trials were performed in different locations using four mustard varieties. The seeds of four mustard varieties namely, NRC DR 2, NRC HB 101, RH 749 and RH 119 were procured from ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur, India. All

Table 1. Potential yield and genetic characteristics of the mustard varieties used in the experiment

Variety	Characteristics
NRC DR 2	It is suitable for timely sown irrigated conditions of Haryana, Punjab, Jammu, parts of Rajasthan and Delhi; The average yield 2.21 t ha^{-1} with 143 days maturity.
NRC HB 101	It is suitable for late sown irrigated conditions of Madhya Pradesh, Uttar Pradesh, Uttarakhand and Eastern Rajasthan. The average yield 1.38 to 1.49 t ha^{-1} with 105-135 days maturity.
RH 749	Timely sown conditions in rainfed areas of Haryana, Punjab, Delhi and parts of Rajasthan. The average yield 2.60-2.80 t ha^{-1} with 146-148 days maturity.
RH 119	Timely sown conditions in rainfed areas of Haryana state. Average yield 1.80-2.00 t ha^{-1} with 145-150 days maturity.

varieties are being widely cultivated by the farmers in India. The characteristic features of these varieties are mentioned in table 1.

Metal analysis

The processed plant samples (leaf+stalk)were digested with di-acid mixture as mentioned earlier (in initial soil and sewage water analysis). After that metal concentration in extractant from plant samples were measured with the help of ICP-OES. Metal uptake and metal transfer factor were calculated as per the formula given below:

Metal uptake (μg plant^{-1}) = Metal concentration in plant (μg g^{-1}) × biomass (g plant^{-1})

$$\text{Metal transfer factors (TF)} = \frac{C_{Plant}}{C_{Soil}}$$

where, C_{Plant} and C_{Soil} are the plant and soil concentrations of heavy metal, respectively.

Statistical analysis

Statistical analysis was done using randomized block design (RBD) with five replications at three locations. The analysis of variance was analyzed through statistical package WASP 2.0. The means were compared with the critical difference (CD) at 5.0% level of significance.

Result and discussion

Effect of locations on metal dynamics

Physicochemical properties of soil and sewage

Organic carbon (OC) and available nutrients (N, P, K, S and B) contents in soil of Bheropura were higher as compared to soils of Islamnagar-II and Islamnagar-I (Table 2). Concentrations of different heavy metals in the irrigation water (sewage) in three locations were more or less similar and in the sub-

Table 2. Physicochemical properties of experiment field

Parameter	Location		
	Islamnagar I	Islamnagar II	Bheropura
pH	8.16	8.12	8.21
EC (dS m^{-1})	0.36	0.33	0.42
OC (%)	0.89	0.96	1.13
Avail N (kg ha^{-1})	489	502	527
Avail P (kg ha^{-1})	14.6	18.9	23.5
Avail K (kg ha^{-1})	590	612	678
Avail S (kg ha^{-1})	46.2	36.9	48.7
Avail B (mg kg^{-1})	0.40	0.59	0.68

ppm range. These values were within permissible limits for irrigation water (Ayers and Westcot 1976). Total heavy metal content of soils of the three locations were more or less in the similar range (Table 3). As compared to the contents in groundwater irrigated area in the same city reported elsewhere (Saha *et al.* 2014), concentrations of Cd, Cr, Cu, Ni and Pb in the experimental soils were 4.6 to 7.2, 3.44 to 4.37, 2.02 to 2.18, 7.65-8.78 and 7.21 to 8.39 times more than metal concentration of IISS field, respectively.
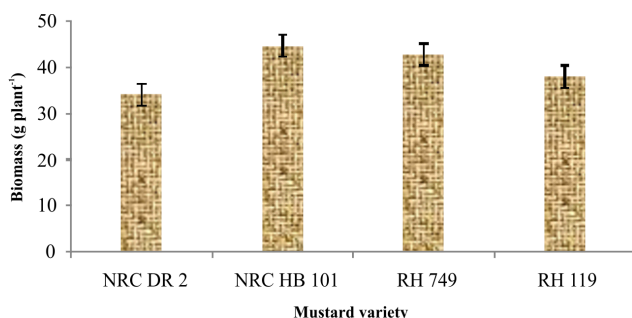
Biomass production of mustard varieties

There were significant difference among the varieties with respect to dry matter production. The highest mean dry biomass was recorded in mustard variety NRC HB 101 with 44.7 g plant^{-1}. The mean biomass of other mustard varieties produced was 42.8, 38.0 and 34.1 g plant^{-1} by RH 749, RH 119 and NRC DR 2, respectively (Fig. 1). Observed difference in biomass production among the varieties might be due to differences in their genetic potential . The similar findings of yield difference among the cultivars of different crops are well established and reported by different researchers (Qdir *et al.* 2004). Nutrient acquisition capacity of cultivars by releasing of chelating agents, ion specific transporters helps in plant growth promotion and production of higher

Table 3. Heavy metal in soil and sewage samples

Location	Cu	Cd	Pb	Cr	Ni	Zn	Mn
				(mg L^{-1})			
Metal in sewage							
Islamnagar I	0.008	0.002	0.014	0.007	0.018	0.017	0.011
Islamnagar II	0.006	0.001	0.013	0.006	0.011	0.029	0.009
Bheropura	0.011	0.001	0.014	0.008	0.004	0.033	0.013
Total metal in soil							
Islamnagar I	82.9	2.9	122.6	110.2	562	72.3	45.6
Islamnagar II	86.3	3.6	126.8	96.3	489	68.9	56.3
Bheropura	89.5	2.3	142.7	122.4	511	89.3	42.9
DTPA- extractable metal in soil							
Islamnagar I	4.89	0.05	1.52	0.02	0.03	1.12	0.09
Islamnagar II	3.58	0.04	1.46	0.01	0.01	1.24	1.02
Bheropura	3.41	0.05	1.58	0.03	0.07	1.33	1.03

biomass (Van Ginneken *et al.* 2007). Influence of soil fertility was found on biomass production among different locations of the experiment. The importance of soil fertility in crop production was well established fact and the good fertile soil produces more crop than the less fertile soil (Havlin *et al.* 2013).

Fig. 1. Dry biomass accumulation of different mustard varieties (mean data of all the three locations)

Metal concentration and metal uptake

In all the three locations, the mustard variety NRC HB 101 had the highest Cu and Mn concentrations in biomass. Cadmium concentration in NRC DR2, NRC HB 101 and RH 119 varieties in all the locations was similar and these were significantly higher as compared to RH 749 variety (Table 4). The RH 749 variety had significantly highest Pb concentration in Islamnagar-I and II; and NRC HB 101 had significantly highest Pb concentration in Bheropura location. The varieties NRC HB 101 in Islamnagar-I and Bheropura locations and NRC DR2 in Islamnagar-II had significantly higher concentration of Cr when compared to other varieties. Whereas, the highest concentration of Ni was found in RH 749 at Islamnagar-I, in RH 119 at Islamnagar-II and in NRC HB 101 at Bheropura (Table 4). The variety RH 119 had the highest Zn concentration in Islamnagar-I and RH 749 in Islamnagar-II and Bheropura.

Table 4. Effect of locations on metal concentration in different mustard cultivars

Location	Variety	Cu (µg g^{-1})	Cd	Pb	Cr	Ni	Zn	Mn
Islamnagar I	NRC DR2	4.70c	0.40a	3.57c	4.90c	0.47c	8.80b	9.53c
	NRC HB 101	12.77a	0.30ab	4.23b	5.87a	1.43ab	19.27a	14.70a
	RH 749	6.33b	0.10c	5.33a	5.43b	1.57a	6.23c	13.20b
	RH 119	12.47a	0.17bc	5.67a	5.57ab	1.27b	19.67a	2.77d
Islamnagar II	NRC DR2	4.67c	0.33a	5.13b	6.63a	0.60c	13.67c	20.70b
	NRC HB 101	9.80a	0.23a	2.37d	2.73c	0.77b	20.53b	36.47a
	RH 749	9.23b	0.10b	6.80a	2.43d	0.47d	30.43a	19.43c
	RH 119	2.70d	0.23a	4.60c	5.63b	1.33a	9.53d	13.83d
Bheropura	NRC DR2	4.37d	0.27a	5.37c	3.97c	0.57b	7.91b	14.27b
	NRC HB 101	9.77a	0.23a	8.17a	10.77a	1.80a	20.37a	28.57a
	RH 749	8.33b	0.10b	4.77d	1.57d	0.27c	21.67a	26.71a
	RH 119	6.77c	0.23a	5.73b	5.83b	0.70b	11.33b	10.83b

The different letter in the same column represents statistically significant differences between treatments (*p*< 0.05)

The metal uptake pattern of mustard cultivars had showed almost identical trend in all the three locations during the study. In Islamnagar-I location, maximum Cu (548 µg plant^{-1}), Cd (3.83 µg plant^{-1}), Zn (27.6 µg plant^{-1}) and Mn (283 µg plant^{-1}) was recorded in NRC HB 101, whereas maximum Pb was accumulated in NRC DR 2 (1.45 µg plant^{-1}). The highest Cr uptake was noted in RH 119 (31.5 µg plant^{-1}) and the maximum Ni uptake was found in RH 749 (8.52 µg plant^{-1}) (Table 5). In case of Islamnagar-II location, the maximum uptake of metals were found in the cultivars NRC HB 101 for (441 µg plant^{-1}), Cd (2.29 µg plant^{-1}), Zn (15.7 µg plant^{-1}) and Mn (748 µg plant^{-1}); NRC DR2 for Pb (1.71 µg plant^{-1}) and Cr (34.0 µg plant^{-1}); and RH 119 for Ni (7.51 µg plant^{-1}). In case of Bheropura location NRC HB 101 had the highest metals uptake when compared to other varieties (Table 5). Among the three locations, total metal removed by the mustard cultivars were in the pattern of Islamnagar-I > Bheropura > Islamnagar-II for Cu, Cd and Zn; Bheropura > Islamnagar-I > Islamnagar-II for Cr, Pb and Ni; Islamnagar-II >Bheropura > Islamnagar-I for Mn.

Different locations were irrigated with sewage water and had difference in soil physicochemical properties (Gurjar and Yadav 2013). So, there were differences in heavy metal uptake by the mustard cultivars in different locations. The results showed that the influence of different locations on metal concentration in mustard cultivars. The concentration in the plant tissues might have been influenced by many factors like heavy metals content and interactions, soil and sewage properties, frequency of sewage water application, other management practices, *etc*. (Yadav *et al.* 2002). Apart from the genetic potential of the plant, environmental and management factors influencing metal concentration in plant tissues had been reported (Prasad and Freitas 2003). The amount of metal absorbed by plants was affected by pH, organic matter, and phosphorus content of soil. The soil properties like particle size, soil mineralogy, pH, organic matter and cation exchange capacity (CEC) and kind of metal fractions and forms could influence the soil-metal interactions and availability of metals (Dermont *et al.* 2008). Further, Clemente *et al.* (2005) reported that addition of organic amendments improved the phytoextraction potential of *B. juncea* at a multi-metal contaminated site. The sewage also had large amount of organic matter can build up SOC which in turn augmented phytoextraction potential of the mustard cultivars. In the current investigation, Bheropura experimental site with high SOC and soil available nutrient showed better performance of remediation than the other sites. Addition of organic matter and fertilizers was also one of the options to augment the phytoremediation process (Dotaniya *et al.* 2019).

Effect of varieties on metal uptake

Different varieties had performed differently regarding metal uptake (Table 6). Mean data of all the three locations showed that the maximum Cu (479 µg plant^{-1}), Cd (2.80 µg plant^{-1}), Cr (38.1 µg plant^{-1}), Ni (9.96 µg plant^{-1}), Zn (26.6 µg plant^{-1}) and Mn (538 µg plant^{-1}) uptakes were found in NRC HB 101, except maximum Pb uptake in NRC DR 2 (1.53 µg plant^{-1}). The pattern of Cu uptake was NRC HB 101 (479 µg plant^{-1}) > RH 749 (340 µg plant^{-1}) > RH 119 (276 µg plant^{-1}) and NRC DR 2 (155 µg plant^{-1}). In case of Cd uptake, the pattern was NRC HB 101 >

Table 5. Effect of locations on metal uptake dynamics

Location	Variety	Cu	Cd	Pb	Cr	Ni	Zn	Mn	Total metal
					(µg plant^{-1})				uptake
Islamnagar I	NRC DR2	150d	1.89b	1.45a	17.4c	2.26c	4.06d	84b	261
	NRC HB 101	548a	3.83a	1.27a	24.8b	8.41a	27.61a	283a	898
	RH 749	266c	0.63b	0.53c	28.9a	8.52a	9.76c	82b	396
	RH 119	473b	2.08b	0.97b	31.5a	7.06b	24.90b	54c	594
Islamnagar II	NRC DR2	158c	1.56b	1.71a	34.0a	3.98b	8.20c	282c	491
	NRC HB 101	441a	2.29a	0.13d	1.5d	2.09c	15.74a	748a	1211
	RH 749	397b	0.92c	0.68c	16.5c	1.13d	14.20ab	591b	1021
	RH 119	105d	0.63c	1.07b	25.9b	7.51a	12.72b	131d	285
Bheropura	NRC DR2	157d	1.16bc	1.43a	21.2c	2.24c	4.71b	113b	301
	NRC HB 101	449a	2.27a	1.90a	87.9a	19.39a	36.67a	582a	1180
	RH 749	358b	0.83c	0.48b	7.4d	0.42d	5.78b	578a	951
	RH 119	250c	1.57b	1.33a	33.4b	4.08b	7.95b	122b	421

The different letter in the same column represents statistically significant differences between treatments (*p*< 0.05)

Table 6. Effect of mustard varieties on metal uptake

Variety	Cu	Cd	Pb	Cr	Ni	Zn	Mn
				(μg plant^{-1})			
NRC DR2	155±4.4d	1.54±0.42b	1.53±0.22a	24.2±8.7c	2.83±1.01d	5.66±2.23d	160±10c
NRC HB 101	479±60a	2.80±0.90a	1.10±0.82b	38.1±4.7a	9.96±3.22a	26.67±9.44a	538±180a
RH 749	340±63b	0.80±0.15c	0.56±0.12c	17.6±4.4d	3.36±0.82c	9.91±2.31c	417±186b
RH 119	276±107c	1.42±0.65b	1.12±0.15b	30.2±3.9b	6.22±1.87b	15.19±5.92b	103±28d

*Mean data of all locations;the different letter in the same column represents statistically significant differences between treatments ($p < 0.05$)

NRC DR 2 > RH 119 = RH 749. The Pb uptake was NRC DR 2 > RH 119 > NRC HB 101 = RH 749. The Cr uptake pattern was NRC HB 101> RH 119> NRC DR 2 > RH 749 (Table 6). The Ni and Zn uptake pattern was in the sequence of NRC HB 101 > RH 119 > RH 749 > NRC DR 2. Manganese uptake of mustard varieties were followed the sequence of NRC HB 101 (538 μg plant^{-1}) > RH 749 (417 μg plant^{-1}) > NRC DR 2 (160 μg plant^{-1}) > RH 119 (103 μg plant^{-1}).

This showed the preference of each cultivar towards metal uptake as controlled by genetic factor of the cultivars (Dotaniya et al. 2018b; Kozminiska et al. 2018). Plants with high affinity for heavy metals had been recommended to restore degraded soils. The uptake of metals or any compound could be influenced by plant species or varietal characteristics (Burken and Schnoor 1996). Grispen et al. (2006) observed that metal uptake variability within the B. napus species of different varieties and accessions. Qadir et al. (2004) assessed ten cultivars of B. juncea for their Cd extraction potential and some cultivars showed higher Cd tolerance than others. Similarly, Gill et al. (2015) also studied the Cr uptake potential in four cultivars of B. napus. Plants could affect the soil by lowering the pH, which affects the availability of the metals; and increasing the bio-availability of heavy metals by chelating agents (Van Ginneken et al. 2007). The dry matter yield must also played a major role in accumulation of large quantity of metals as evidenced from the result of maximum uptake of metals by cultivar NRC HB 101 with the highest dry matter yield. The similar concept of hyperaccumalating plants that produce large amounts of biomass using established crop production and management practices to be selected for successful phytoremediation had been envisaged. Further, plant varieties with better remediation properties had to be selected for remediation purpose (Prasad and Freitas 2003). The heterogeneous distribution of metals as that of current study were real and mostly happen in many contaminated sites depicted the clear picture than the homogeneous conditions (Podar et al. 2004). Release of enzymes, chelating agents and metal transporters were the most important mechanisms of phytoremediation of metal contaminated sites (Mourato et al. 2015). Though the current study comparatively assessed the four Indian mustard varieties actual mechanism involved and exhibited by each cultivars was not known and need to be studied using advanced technologies like genomics, transcriptomics, proteomics and metabolomics to establish the genome, transcript, protein and metabolite levels involved in heavy metal stress, which was beyond the scope of the current study. However, among the cultivar used NRC HB 101 performed better in all the three locations, and could be recommended for remediation of multi-metal contaminated sites.

Metal transfer factor

Transfer of a metal concentration from the soil to plant parts can be calculated by metal transfer factor. In this experiment, we have computed the phytoextraction capacity of different mustard varieties (Fig. 2). Experimental results showed that most of the varieties extract most of the metals from sewage irrigated soils. Among mustard varieties, NRC HB 101 showed higher accumulation potential (more than one) as compared to rest of the varieties at all the locations except Islamnagar I. If we compared the individual phytoextraction potential of all the varieties, it was less than one, which showed most of the varieties are not performed as a higher accumulator for a particular metal at all the locations. The RH 749 also showed phytoextraction potential after NRC HB 101 at Islamnagar II and Bheropura location, whereas NRC DR 2 better performed at Islamnagar I. The transfer of metal from soil to plant part much affected by genetic and the soil properties like SOM, pH, other metal ions and also by the humus-metal complex formed in rhizospheric zone of the soil. Sewage irrigated soils are having higher
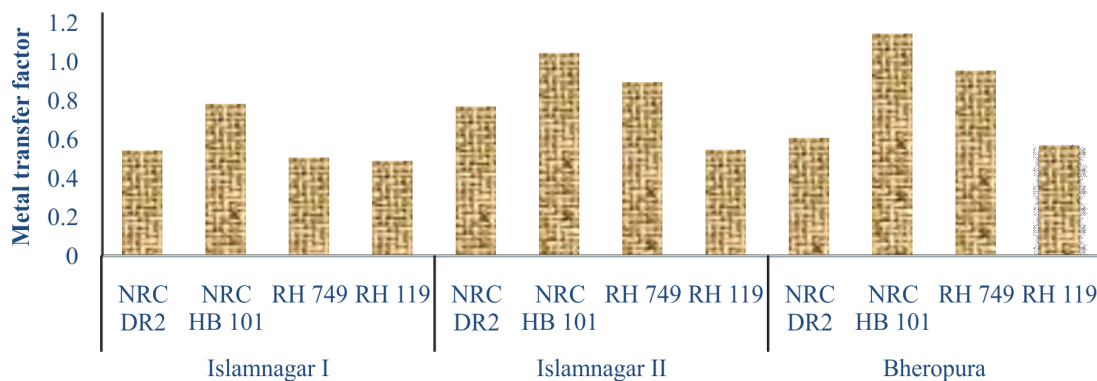
Fig. 2. Phytoextraction potential of different mustard varieties

amount of SOM and convert the metal concentration in organic mater bound form and reduced active concentration level in soil solution (Mourato *et al.* 2015).

Conclusions

Sewage irrigation is much popular among the peri-urban areas for agricultural production. Most of the agricultural fields located on the banks of sewage channel are irrigated using sewage water by willingly or to meet the scarcity of fresh water. Sewage waters contain significant amount of plant nutrients and organic matter which reduce the use of chemical fertilizers. They also contain meager amount of heavy metals which impact the soil and plant health and productivity. Long-term application of sewage for irrigation accumulates significant amount of metals in crop fields. Indian mustard is well known for remediation of contaminated areas and is largely adopted across the globe. Experimental results showed that among the four mustard varieties raised in the study, the cultivar NRC HB 101 has recorded the maximum uptake of Cu, Cd, Cr, Ni, Zn and Mn and also performed as a metal accumulator, whereas variety NRC DR 2 has accumulated the highest amount of Pb from soils. These kinds of information are very much useful for formulation of metal remediation strategies in sewage or industrial irrigated metal contaminated areas.

References

Ayers, R.S. and Westcot, D.W. (1976) *Water quality for agriculture*. FAO irrigation and drainage paper 29, FAO, Rome.

Ali, H., Khan, E. and Sajad, M. (2013) Phytoremediation of heavy metals-concepts and applications. *Chemosphere* **91**, 869–881.

Burken, J.G. and Schnoor, J.L. (1996) Phytoremediation: plant uptake of atrazine and role of root exudates. *Journal of Environmental Engineering* **122**, 958–963.

Clemente, R., Walker, D.J. and Bernal, M.P. (2005) Uptake of heavy metals and as by *Brassica juncea* grown in a contaminated soil in Aznalcollar (Spain): The effect of soil amendments. *Environmental Pollution* **138**, 46–58.

Dermont, G., Bergeron, M., Mercier, G. and Richer-Laflèche, M. (2008) Metal-contaminated soils: remediation practices and treatment technologies. *Journal of Hazardous, Toxic and Radioactive Waste* **12**, 188–209.

Dotaniya, M.L., Rajendiran, S., Meena, V.D., Coumar, M.V., Saha, J.K., Kundu, S. and Patra, A.K. (2018b) Impact of long-term application of sewage on soil and crop quality in Vertisols of central India. *Bulletin of Environmental Contamination and Toxicology* **101**, 779–786.

Dotaniya, M.L., Dotaniya, C.K., Solanki, P., Meena, V.D. and Doutaniya, R.K. (2020) Lead contamination and its dynamics in soil–plant system. In *Lead in Plants and the Environment. Radionuclides and Heavy Metals in the Environment* (D.K. Gupta, S.Chatterjee and C. Walther, Eds.), Springer, Cham doi.org/10.1007/978-3-030-21638-2_5

Dotaniya, M.L., Meena, V.D., Rajendiran, S., Coumar, M.V., Sahu, A., Saha, J.K. and Patra, A.K. (2018a) Impact of long-term application of Patranala sewage

on carbon sequestration and heavy metal accumulation in soils. *Journal of the Indian Society of Soil Science* **66**, 310-317.

Dotaniya, M.L., Saha, J.K., Rajendiran, S., Coumar, M.V., Meena, V.D., Kundu, S. and Patra A.K. (2019) Chromium toxicity mediated by application of chloride and sulphate ions in Vertisol of Central India. *Environmental Monitoring and Assessment* **191**, 429.

Gill, R.A., Zang, L., Ali, B., Farooq, M.A., Cui, P., Yang, S., Ali, S. and Zhou, W. (2015) Chromium-induced physico-chemical and ultrastructural changes in four cultivars of *Brassica napus* L. *Chemosphere* **120**, 154–164.

Grispen, V.M.J., Nelissen, H.J.M. and Verkleij, J.A.C. (2006) Phytoextraction with *Brassica napus* L.: A tool for sustainable management of heavy metal contaminated soils. *Environmental Pollution* **144**, 77–83.

Gurjar, D.S. and Yadav, B.R. (2013) Seasonal variation in pH, salinity, nitrate, floride and heavy metals in irrigated soils of Southwest region of Delhi, India. *Journal of the Indian Society of Soil Science* **61**, 63-66.

Havlin, J.L., Tisdale, S.L., Nelson, W.L. and Beaton, J.D. (2013) *Soil Fertility and Fertilizers*. Pearson Publication, India.

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

Kozminiska, A., Wiszniewska, A., Hanus-Fajerska, E. and Muszynska, E. (2018) Recent strategies of increasing metal tolerance and phytoremediation potential using genetic transformation of plants. *Plant Biotechnology Reports* **12**, 1–14.

Lindsay, W.L. and Norvel, W.A. (1978) Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal* **42**, 421-428.

Meena, V.D., Dotaniya, M.L., Saha, J.K., Meena, B.P., Das, H., Beena and Patra, A.K. (2020) Sustainable C and N management under metal-contaminated soils. In *Carbon and nitrogen cycling in soil* (Datta, R., Meena, R., Pathan, S. and Ceccherini, M., Eds.), Springer, Singapore, pp. 293-336.

Mourato, M.P., Moreira, I.N., Leitao, I., Pinto, F.R., Joana, R.S. and Martins, L.L. (2015) Effect of heavy metals in plants of the genus *Brassica*. *International Journal of Molecular Sciences* **16**, 17975-17998.

Podar, D., Ramsey, M.H. and Hutchings, M.J. (2004) Effect of cadmium, zinc and substrate heterogeneity on yield, shoot metal concentration and metal uptake by *Brassica juncea*: Implications for human health risk assessment and phytoremediation. *New Phytologist* **163**, 313–324.

Prasad, M.N.V. and Freitas, H.M.D.O. (2003) Metal hyperaccumulation in plants—biodiversity prospecting for phytoremediation technology. *Electronic Journal of Biotechnology* **6**, 110–146.

Qadir, S., Qureshi, M.I., Javed, S. and Abdin, M.Z. (2004) Genotypic variation in phytoremediation potential of *Brassica juncea* cultivars exposed to Cd stress. *Plant Science* **167**, 1171–1181.

Rascio, N. and Navari-Izzo, F. (2011) Heavy metal hyperaccumulating plants: how and why do they do it? And what makes them so interesting?. *Plant Science* **180**, 169–181.

Rathore, S.S., Shekhawat, K., Dass, A., Kandpal, B.K. and Singh, V.K. (2019) Phytoremediation mechanism in Indian mustard (*Brassica juncea*) and its enhancement through agronomic interventions. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences* **89,** 419–427.

Saha, J.K., Selladurai, R., Coumar, M.V., Dotaniya, M.L., Kundu, S. and Patra, A.K. (2017) *Soil Pollution an Emerging Threat to Agriculture*. Springer, Singapore.

Van Ginneken, L., Meers, E. Guisson, R., Ruttens, A., Elst, K.,Tack, F.M.G. Vangronsveld, J., Diels, L. and Dejonghe, W. (2007) Phytoremediation for heavy metal contaminated soils combined with bioenergy production. *Journal of Environmental Engineering and Landscape Management* **15**, 227–236.

Yadav, R.K., Goyal, B., Sharma, R.K., Dubey, S.K. and Minhas, P.S. (2002) Post-irrigation impact of domestic sewage effluent on compositioin of soils, crops and ground water – a case study. *Environment International* **28**, 481-486.