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Performance of castor in heavy metal polluted soils under the treatment of various decontaminants

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ABSTRACT

In order to find out the performance of castor under decontaminant treated heavy metal polluted soils, an experiment was conducted at Students Farm, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad, during *kharif* 2016 to study the performance of castor in heavy metal polluted soil under the treatments of various decontaminants (various dosages of phosphorus as well as, quick lime). The dry matter before flowering, and stalk yield at harvest of castor varied from 429 to 516, 1460 to 1758 kg/ha, respectively. Among the different decontaminants highest dry matter yield and stalk yield (516 and 1758 kg/ha at before flowering and harvest) and seed yield (1720 kg/ha) was obtained in T_5 (RDF+CaO @ 2 t/ha), which was significantly superior over all other treatments and on par with T_4 (RDF+CaO @ 1 t/ha), and per cent increase over RDF was 20.41 and 23.56, respectively for stalk, and seed yield of castor. Decontamination treatments had reduced the mean Pb, Cd, Ni and Co contents of castor to 4.51, 0.65, 0.95 and 0.63 mg/kg, and increased mean uptake to 7.62, 1.17, 1.69 and1.09 g/ha respectively, for Pb, Cd, Ni and Co in seed at harvest. The Pb, Cd, Ni and Co contents of soil after harvest of the castor crop ranged from 17.11, 0.79, 1.89 and 1.22 mg/kg in the reference control and decreased to 14.60, 0.68, 1.67 and1.02 with RDF+CaO @ 2 t/ha treatment. The reduction in Pb, Cd, Ni and Co concentration in post-harvest soil was more due to Cao at different levels when compared to high phosphorus.

Introduction

In India, due to rapid industrial development during the last few decades, disposal of industrial effluents has become serious problem, and application of those effluents to land has become a common means of disposal in the recent past (Solanki *et al*., 2019; Bhardwaj *et al.,* 2020). Besides being a useful source of plant nutrients, these effluents often contain high amounts of various organic and inorganic materials as well as heavy metals. Such industrial effluents when mixed with water used for irrigation, becomes potential threat to soil physical, chemical and biological environment, as a whole to the soil health and ecosystem functionality (Ruhela *et al.,* 2021). The unscientific disposal of untreated or undertreated effluents has resulted in huge accumulation of heavy metals in soil and finally gets entry into the human and animal food chain through the crops grown on it (Ruhela *et al.,* 2022). Restriction of crop cultivation in such toxic metal polluted soils, is the best option to check the entry of such hazardous heavy metals into the day today food chain of the animals. But looking at the ever-increasing food demand of the globe, it is not practically possible to restrain those areas from

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growing crops. Thus, the real challenge to a soil scientists lies in restoring these soils to normal levels within reasonable time and cost, as non-renewable sources like soils cannot be afforded to be left unused. The heavy metal contaminated soils can be remediated through two approaches *i.e.,* phytoremediation (Ghosh and Singh, 2005; Bhutiani *et al.,* 2019a and b) and/or chemical decontamination (Balachandra *et al*., 2021). Remediation methods available for reducing the harmful effects of these heavy metals at their contaminated sites include chemical, physical and biological techniques (Padhan *et al*., 2021). These can be grouped into two categories *i.e*., ex-situ and in-situ methods Reed *et al* (1992). The conventional ex-situ methods for remediating the polluted soils are based on excavation, detoxification and/or destruction of contaminants physically or chemically, as a result the contaminants undergo stabilisation, solidification, immobilisation, incineration or destruction (Padhan *et al*., 2021 and Balachandra *et al*., 2021). Identification of chemical amendments followed by evaluation of their cost effectiveness can be a key element in a sustainable land management strategy for reclaiming heavy metal contaminated agricultural lands. In this backdrop the experiment was taken up to study the performance of castor on application of various decontaminants in a heavy metal polluted soil.

Material and Methods

An experiment was setup to know the effect of inorganic amendments in abetting the heavy metals pollution in a polluted soil at Student Farm, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad. The basic properties of the soil were analyzed using standard protocol Marchi *et al*. (2009). The soil of the experimental site was sandy clay loam in texture, slightly acidic in reaction, normal in soluble salt content with available N (275 kg/ha), P_2O_5 (34 kg/ha) and K_2O (275 kg/ha) and DTPA extractable Pb (20.24 ppm), Cd (1.11 ppm), Ni (2.27 ppm) and Co (2.27 ppm). The experiment was laid out in randomized block design with 5 treatments and 4 replications with castor as test crop. The treatments include T_1 RDF (only), $T_{2:}$ (T_1)+High phosphorus 150%, $T_{3:}$ (T_1) + High phosphorus 200%, $T_{4:}$ (T_1)+lime (CaO)1t/ha, $T_{5:}$ (T_1)+lime (CaO) 2 t/ha. The recommended dose of fertilizers for castor was 60: 40: 30 kg N: P_2O_5: K_2O ha^{-1} as per the PJTSAU, Telangana and were applied in the form of urea, Single Super Phosphate (SSP) and Muriate of Potash (MOP) respectively. High amount of phosphorus and quick lime were applied as per the treatments and were mixed thoroughly with soil to ensure uniform distribution of the decontaminants in the soils of respective plots. The crop was sown on 20^{th} of June 2016 and the irrigation and plant protection measures were taken up as and when required. The representative plant samples were collected from all the treatments before flowering (whole above ground biomass) and at harvest stage (stem and seeds separately) of the crop. The soil samples collected after harvesting of the crop and the plant samples collected during different growth stages were analyzed in order to find out the heavy metal concentration in each sample.

Results and Discussion

Effect of applied decontaminants on dry matter and seed yield (kg/ha) of Castor.

Dry matter is the expression of growth and development of different morphological components and it is directly related to the yield. Dry weight of plants before flowering and stalk and seed yield at harvest are given in table 1, 2 and 3 respectively.

Dry weight of plants before flowering

The dry weight of the castor plants collected before flowering ranged from 429 to 516 kg/ha with a mean of 482 kg/ha. Decontaminant treatments were found effective in bringing about significant increase in the dry weight of plants collected before flowering over the control. Also, there was significant effect of application of the two decontaminants on dry weight of castor. On an average, the dry weight of plants obtained under the decontaminant treatments i.e. high phosphorus at 150 and 200% or lime application at 1 and 2 t/ha are 470, 472, (513 and 516 kg/ha) respectively. But the dry matter yield obtained under various doses of P application were at par with each other and similar results were also obtained in case of quick lime treatments. In terms of dry weight and percentage, the dry weight of plants obtained under decontaminants contaminant treatments increased by 482 kg/ha and 14.91% over the control one. The increase in dry weight of plants under decontaminant application might be due to

Table 1: Direct effect of applied decontaminants on dry matter yield, heavy metal contents and uptake by castor before flowering (*kharif*, 2016)

Treatments	Dry matter (kg/ha)	Heavy metal contents (mg/kg)					Heavy metal uptake (g/ha)				
		Pb	Cd	Ni	Co	Total metal load	Pb	Cd	Ni	Co	Total metal uptake
T1-100% RDF	429	27.01	0.78	3.47	1.50	32.76	11.59	0.33	1.49	0.64	14.05
T2-T1+ High phosphorus 150%	470	25.01	0.70	3.36	1.47	30.54	11.75	0.33	1.58	0.69	14.35
T3-T1+ High phosphorus 200%	472	24.86	0.71	3.33	1.44	30.34	11.73	0.34	1.57	0.68	14.32
T4-T1+ lime (CaO) 1 t/ha	513	22.89	0.69	3.23	1.32	28.13	11.74	0.35	1.66	0.68	14.43
T5-T1+ lime (CaO) 2 t/ha	516	21.70	0.69	3.15	1.32	26.86	11.20	0.36	1.63	0.67	13.86
Mean of Decontaminants	493	23.62	0.70	3.27	1.39	28.97	11.61	0.34	1.61	0.68	14.24
Overall mean	482	24.18	0.71	3.30	1.41	29.60	11.60	0.34	1.59	0.68	14.21
S. Em±	13.39	0.65	0.02	0.08	0.05	0.99	0.15	0.02	0.06	0.02	0.21
CD (*P=0.05*)	40.00	1.96	0.07	0.23	0.16	2.98	NS	NS	NS	NS	NS

Table 2: Direct effect of applied decontaminants on stalk yield, heavy metal contents and uptake by castor at harvest (*kharif*, 2016)

Treatments	Stalk yield (kg/ha)	Heavy metal contents (mg/kg)					Heavy metal uptake (g/ha)				
		Pb	Cd	Ni	Co	Total metal load	Pb	Cd	Ni	Co	Total metal uptake
T_1-100% RDF	1460	12.39	3.71	2.40	1.04	19.54	18.09	5.42	3.50	1.52	28.53
T_2-T_1+ High phosphorus 150%	1605	11.68	3.45	2.34	1.00	17.66	18.75	4.51	3.58	1.51	28.34
T_3-T_1+ High phosphorus 200%	1608	11.45	3.42	2.29	0.94	17.13	18.59	4.26	3.26	1.43	27.55
T_4-T_1+ lime (CaO) 1 t/ha	1751	10.54	3.16	2.10	0.84	15.84	18.45	4.41	3.43	1.44	27.72
T_5-T_1+ lime (CaO) 2 t/ha	1758	10.29	3.15	2.08	0.82	14.64	18.09	4.24	2.00	1.41	25.74
Mean of Decontaminants	1681	10.99	3.30	2.20	0.90	16.32	18.47	4.35	3.07	1.45	33.48
Overall mean	1636	11.27	3.38	2.24	0.93	16.96	18.39	4.57	3.16	1.46	33.53
S. Em±	47	0.31	0.09	0.03	0.03	0.59	0.24	0.42	0.53	0.05	0.96
CD (*P=0.05*)	140	0.92	0.28	0.10	0.09	1.78	NS	NS	NS	NS	NS

reduced concentration and activity of toxic metals in soils there by reducing their detrimental effects on plants growth (Mathavan *et al*., 2001).

Yield at harvest

The stalk (table 2) and seed (table 3) yield collected at harvest varied from 1460 to 1758 and 1392 to 1720 with a mean of 1644 and 1587 kg/ha, respectively. Significant effect of decontaminants was seen on the stalk and seed yield over control (RDF). There was significant increase in stalk and seed yield of castor at harvest due to application of decontaminants but there was no significant difference in stalk or seed yield of castor within the doses of applied decontaminants i.e. high phosphorus (150 and 200%) and lime application (1 or 2 t/ha). Highest yield of stalk (1758 kg/ha) and seed (1720 kg/ha) was recorded when lime application was done along with RDF @ 2 t/ha. Increase in yields of castor by the application of inorganic amendments may be attributed to suppression of heavy metals toxicity, improving soil physical condition (Park *et al.*, 2011) and increase in mineral nutrition (Hamid *et al.*, 2019). Similar results were also observed by Ranjeet Kumar (2016) who reported a significant increase in yields of spinach due to application of organic and inorganic amendments in contaminated soil at New Delhi. The performance of treatments in terms of seed yield were in the order of $T_5 > T_4 > T_3 > T_2 > T_1$. Application of quick lime resulted in 23 per cent increase in seed yield of castor over control which may be due to improved workability of soil, soil aggregation, porosity and aeration which might have resulted in increased seed yield of castor. Similar results were reported by Daur and Tatar (2013). Muhammad and Khattak (2011) in wheat and Chamun *et al.* (2011) in rice also found the similar observation where increase in yield was obtained due to application of gypsum along with FYM. Muhammad *et al.* (2017) observed higher wheat yields with gypsum application in an effluent irrigated field at Multan in Pakistan, Ahmad *et al.* (2017) also reported higher wheat yields with gypsum application as a amendment in alkaline soils using irrigation water polluted with Cd and Pb for maize. Due to inherent soil acidity in area, liming resulted in increased yield. The positive effect of high phosphorus and lime in trace metal contaminated soil may be due to the reduction in bioavailability of toxic metals by complexation and adsorption. Similar results were reported earlier by Mathavan *et al.* (2001[a]) Bolan *et al.* (2003) and Rattan *et al.* (2005).

Effect of decontaminants on concentration of heavy metals in castor (before flowering)

Lead, cadmium, nickel and cobalt contents in the dry matter samples collected before flowering in the reference control (only RDF) treatment were 27.01, 0.78, 3.47 and 1.50 mg/kg, respectively. Application of decontamination treatments reduced the mean heavy metal content in the dry matter to 23.62, 0.70, 3.27 and 1.39 mg/kg, respectively. Though there was a reduction in heavy metal contents i.e. (Pb, Cd, Ni and Co) in the samples collected, but the concentrations were at par with each other were (table 1). The uptake of heavy metals (Pb, Cd, Ni and Co) in the dry matter collected before flowering were increased by the decontamination treatments except T_5 when compared to RDF (11.59, 0.33, 1.49 and 0.64 g/ha, respectively), but the increase was found to be non significant. The total heavy metal uptake varied between 13.86 and 14.35 g/ha (table 1).

Effect of decontaminants on concentration of heavy metals by castor at harvest

Heavy metal contents and uptake of stalk and seed were presented in (table 2 and 3). Heavy metal contents showed a decrease both in the seed and stalk with the application of decontaminants. Heavy metals viz., Pb, Cd, Ni and Co in the control (RDF) were 12.39, 3.71, 2.40 and 1.04 mg/kg, respectively in stalk and 5.17, 0.82, 1.17 and 0.76 mg/kg, respectively in seed which decreased to 10.99, 3.30, 2.20 and 0.90 mg/kg, respectively in stalk and 10.21, 2.46, 1.85 and 0.82 mg/kg, respectively in seed at maturity. There was significant reduction in Pb, Cd, Ni and Co contents in the stalk and seed noticed in the lime applied treatment at both the doses (1 and 2 t/ha) over control (RDF) and the reduction in Ni and Co concentration in stalk and Pb, Cd, Ni and Co in seed was also seen at high phosphorus application *i.e.,* P @ 200%. The mean total metal load ranged from 14.64 to 19.54 mg/kg in stalk and 6.74 to 7.92 mg/kg in seed.The heavy metal uptake was not significantly influenced by the decontamination treatments. The mean heavy metal uptakes recorded by different treatments were 18.39, 4.57, 3.16 and 1.46 and 7.53, 1.17, 1.68 and 1.09 g/ha in stalk, and seed, respectively.

The total heavy metal uptakes ranged from 25.74 to 28.53 and 11.02 to 11.77 g/ha in the stalk and seed, respectively. Beneficial effect of organic and inorganic amendments on heavy metal conc of plants were also observed by various scientists. For example, Park *et al.*, 2011 observed that Pb content in sunflower shoot reduced by 60-80% with amendments application in sewage polluted soils. Ranjeet Kumar (2016[a]) found the significant reduction of Pb in plant parts of spinach in amended polluted soil when compared to non amended polluted soil at New Delhi. Pandit *et al.*, 2017 also reported that the application of amendment decreased the Cd concentration to an extent of 61 percent in spinach plant compared to unamended treatment in a contaminated soil. The immobilization of Cd and Pb through adsorption, complexation and precipitation phenomena, may have resulted in reduced phytotoxicity and accumulation in plants (Geebelen *et al.*, 2002;

Table 3: Direct effect of applied decontaminants on seed yield, heavy metal contents and uptake by castor at harvest (*kharif*, 2016)

Treatments	Seed yield (kg/ha)	Heavy metal contents (mg/kg)					Heavy metal uptake (g/ha)				
		Pb	Cd	Ni	Co	Total metal load	Pb	Cd	Ni	Co	Total metal uptake
T_1-100% RDF	1392	5.17	0.82	1.17	0.76	7.92	7.20	1.14	1.63	1.06	11.02
T_2-T_1+ High phosphorus 150%	1549	4.84	0.79	1.11	0.71	7.45	7.50	1.22	1.72	1.10	11.54
T_3-T_1+ High phosphorus 200%	1560	4.76	0.77	1.08	0.70	7.31	7.43	1.20	1.68	1.09	11.40
T_4-T_1+ lime (CaO) 1 t/ha	1716	4.54	0.67	1.01	0.64	6.86	7.79	1.15	1.73	1.10	11.77
T_5-T_1+ lime (CaO) 2 t/ha	1720	4.51	0.65	0.95	0.63	6.74	7.76	1.12	1.63	1.08	11.59
Mean of Decontaminants	1636	4.66	0.72	1.04	0.67	7.09	7.62	1.17	1.69	1.09	11.58
Overall mean	1587	4.76	0.74	1.06	0.69	7.26	7.53	1.17	1.68	1.09	11.47
S. Em±	52	0.10	0.01	0.02	1.07	0.20	0.22	0.03	0.05	0.03	0.26
CD (*P=0.05*)	156	0.32	0.04	0.05	0.04	0.60	NS	NS	NS	NS	NS

Table 4: Heavy metal status (mg/kg) in post-harvest soil of castor under different decontamination treatments (DTPA)

Treatments	Available heavy metal status (mg/kg)			
	Pb	Cd	Ni	Co
T_1-100% RDF	17.11	0.79	1.89	1.22
T_2- T_1+High phosphorus 150%	16.45	0.76	1.84	1.19
T_3-T_1+ High phosphorus 200%	16.15	0.75	1.78	1.15
T_4-T_1+ lime (CaO) 1 t/ha	15.64	0.71	1.73	1.06
T_5-T_1+ lime (CaO) 2 t/ha	14.60	0.68	1.61	1.02
Mean of Decontaminants	15.71	0.73	1.74	1.11
Overall mean	15.99	0.74	1.77	1.13
S. Em±	0.51	0.02	0.05	0.04
CD(*P=0.05*)	1.53	0.06	0.16	0.12

Table 5: Heavy metal status (mg/kg) in post-harvest soil of castor under different decontamination treatments (AB-DTPA)

Treatments	Available heavy metal status (mg/kg)			
	Pb	Cd	Ni	Co
T_1-100% RDF	17.01	0.75	1.87	1.20
T_2- T_1+High phosphorus 150%	16.43	0.74	1.81	1.15
T_3-T_1+ High phosphorus 200%	16.12	0.71	1.77	1.12
T_4-T_1+ lime (CaO) 1 t/ha	15.55	0.67	1.71	1.04
T_5-T_1+ lime (CaO) 2 t/ha	14.41	0.63	1.58	1.00
Mean of Decontaminants	15.63	0.69	1.72	1.08
Overall mean	15.90	0.70	1.75	1.10
S. Em±	0.56	0.02	0.06	0.04
CD(*P=0.05*)	1.69	0.07	0.17	0.11

Seaman *et al.*, 2003). Rehman *et al.* (2015) also found that gypsum application decreased the grain and straw Cd concentration in wheat and rice crops grown on contaminated soil at Faisalabad in Pakistan. Gypsum might be better amendments for *insitu* immobilization of Cd and some other heavy metals due to its low cost and frequent availability (Illere *et al.*, 2004). Ahmad *et al.* (2017) also found the reduction of Cd and Pb concentration in wheat with the addition of gypsum at Faisalabad. The percentage reduction of all the heavy metal content due to application of decontamination treatments over the control in castor crop grown on polluted soil at harvest in seed ranged from 6.38 to 12.76 for Pb, 3.65 to 20.73 for Cd, 5.12 to 18.80 per cent for Ni, and 7.04 to 20.63 per cent for Co. The maximum percentage reduction in heavy metals over the control was in T_5 where with CaO @ 2 t/ha. The reduction in heavy metals contents in seed with the best treatment were in order as Cd>Co>Ni>Pb. According to Bolan *et al*. (2003[a]) Ca^{+2} addition through lime inhibited the translocation of Cd, Pb and other heavy metals from root to shoot as these metals were accumulated primarily on cell walls of roots with only limited amounts translocated to shoot and seed. Stabilization of metals by these amendments through adsorption, complexation and reduction reaction (Brown *et al.* 2003; O' Dell *et al.* 2007).

Heavy metal status (mg/kg) in post-harvest soil

DTPA and AB-DTPA extractable Heavy metal status

There was a significant influence of applied decontaminants on the status of DTPA extractable heavy metal status at maturity. There was a depletion of available heavy metals due to application of two different sources of decontamination treatments. The contents varied from 14.60 to 17.11, 0.68 to 0.79, 1.61 to 1.89 and 1.02 to 1.22 mg/kg, respectively for Pb, Cd, Ni and Co at different levels of applied decontaminants. The mean concentration of extractable heavy metals at maturity were 15.99, 0.74, 1.77 and 1.13 mg/kg, respectively of Pb, Cd, Ni and Co (table 4).Though the variation in contents between different levels and sources were not significant except lime @ 2 t/ha, where there was a depletion in extractable heavy metal status as extracted by AB-DTPA due to application of decontaminants at different levels. The mean AB-DTPA extractable heavy metals i.e. Pb, Cd, Ni and Co contents in the soils after the harvest of direct crop of castor were 15.90, 0.70, 1.75 and 1.10 mg/kg, respectively (table 5). The reduction in Pb, Cd, Ni and Co in post harvest soils were more due to Cao (quick lime) at different levels as compared to application of high doses phosphorus. The reduction of available heavy metal contents in post harvest soils with the application of CaO might be due to the stabilization of metals by amendments (Mathavan 2001).

Conclusion

From our study it appeared that inorganic amendment application might have decreased the available heavy metal contents in the soil and thereby providing more congenial atmosphere for castor growth due to reduction in their contents in plant. Though the application of quick lime did not contribute to mineral nutrition of the plant directly, it can be concluded that these amendments helped in increasing seed yield of castor grown on polluted soils by reducing detrimental effects of toxic metal in soil for plant growth and neutralizing the inherent soil acidity. Solubility and mobilize of heavy metals of soils was reduced due to amendment application and hence their toxicity could be reduced. It was observed that available heavy metal contents in soils decreased in amendment treated soils as compared to unamended one. A reason for decrease in plant available heavy metals in soils may be due to the stabilization of metals by amendments in order to form insoluble complexes restricting its activity in soil.

Conflict of interest

The authors declare that they have no conflict of interest.

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