Remediation of chromium contaminated soils: Potential for phyto and bioremediation

Mahimairaja Santiago and Shenbagavalli Santhamani

Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore, India, Email rajasmahimai@yahoo.co.in

Abstract

Long term disposal of tannery wastes has resulted in extensive contamination of agricultural land and water sources in many parts of India. Chromium (Cr), a toxic heavy metal, is a major contaminant in tannery wastes and its accumulation in soil and water is an environmental issue of increasing public concern in India, particularly in Tamil Nadu. Remediation of Cr-contaminated soils is a challenging task which may not only help in sustaining agriculture, but also in minimizing adverse environmental impacts. We examined the potential of phytoremediation and bioremediation techniques suitable for Cr-contaminated soils. Non-edible flower crops were found suitable in remediation as they grow well under Cr-rich effluent irrigation. Amongst the plants examined, *Jasminum* species showed a high degree of tolerance towards soil Cr. While a mustard crop did not establish, a sunflower crop established very well and exhibited higher tolerance towards soil Cr. However, the accumulation of Cr in seeds is likely to diminish its potential for phytoremediation. Application of biological wastes namely, coir pith and poultry manure, to Cr-contaminated soil was found effective in reducing the bioavailable fractions of Cr mainly by forming organic complexes and demonstrated their potential in bioremediating the Cr-contaminated soil.

Key Words

Heavy metals, Cr-hyper accumulators, tanneries, bioavailability, poultry manure, coir pith.

Introduction

The tanning industry is one of the major sources of pollution in Tamil Nadu, India as it disposes large quantities of effluents and sludge rich in chromium (Cr) and salts. The indiscriminate disposal of such wastes into rivers and onto land has resulted in extensive degradation of productive agricultural land and water sources. There are several contaminated sites in Vellore, Erode and Dindigul districts in Tamil Nadu, where, more than 60 per cent of Indian tanneries are located. Assessment of Cr in contaminated soils in Vellore district showed that the soils around tannery industries are severely contaminated with Cr and in most places exceeded the maximum threshold limit prescribed in different countries. The Cr concentration in ground waters was also much higher than the normal average background value reported in different parts of India (Mahimairaja *et al.* 2000).

Phytoremediation is an emerging technology which involves the use of metal-accumulating plants or metal-tolerant plants for remediating metal contaminated soils. Some plants have inherent capacity to absorb and hyperaccumulate heavy metals in their tissues and such capacity can be harnessed to remove toxic heavy metals from contaminated soils. Bioremediation of contaminated soils is a widely accepted technology in which native or introduced microorganisms and/or biological wastes such as compost, animal manures and plant residues are used to detoxify or transform toxic Cr to less toxic forms. Though it has several limitations, this technology holds continuing interest because of its cost-effectiveness. We examined the potential of certain crops (flower, and oilseed crops) and biological wastes (coir pith and poultry manure), in remediating the Cr-contaminated soil.

Methods

Field experiments

A field experiment was conducted on a sandy loam soil (*Typic ustropept)* to examine the growth of plants and accumulation of Cr in plants under Cr-rich effluent irrigation. The soil was slightly saline (pH 8.2; EC 0.23 dS/m) with a cation exchange capacity of 13.4 cmol (p+)/kg. The flower crops *viz*., *Jasminum sambac* (Gundumalli), *Jasminum grandiflorum* (Jathimalli), *Polianthus tuberosa* (Tuberose) and *Nerium oleander* (Nerium) were evaluated for their phytoremediation potential. The growth and marketable flower yield of plants and the accumulation of Cr in plant parts were examined. In another field experiment, the growth and Cr accumulation in two field crops *viz*., sunflower and mustard grown on soils amended with different levels of Cr-laden tannery sludge at rates equivalent to 2500, 5000 and 7500 mg Cr per kg soil were examined. The growth of crops and the Cr accumulation in different parts were examined. The plant samples (flowers, leaves and roots) were collected after 10 months, dried, ground and digested with aqua-regia at 110^{o}C for 2 hrs. After filtration, the Cr was determined using an Atomic Absorption Spectrophotometer (Varian SpectrAA-200) using air-acetylene flame (USEPA 1979).

Laboratory experiment

The potential of some biological wastes *viz*., coir pith (a waste product from coconut industry) and poultry manure in remediation of Cr-contaminated soil was assessed by examining their effect on the transformation of Cr in sludge amended soils in a closed incubation experiment. Chrome sludge (29560 mg Cr/kg) was mixed with either 100 g clay loam (*Typic haplustert*) or silt clay loam (*Typic ustropept*) at a rate equivalent to 3000 mg Cr/kg soil. The coir pith and poultry manure were added at a rate equivalent to 12.5 t/ha and 5 t/ha, respectively. After thorough mixing of soil, sludge and coir pith / poultry manure, the soil-mixture was incubated in 150 ml plastic cups at field capacity moisture (0.58 g/g). The moisture content was maintained throughout the incubation. The transformation of Cr was examined by determining the different fractions of Cr in soil following a sequential fractionation procedure (Noble and Hughes 1991).

Results

Chromium accumulation in flower crops

The results of field experiment showed that considerable amount of Cr was accumulated in flower crops due to irrigation with tannery effluent. The Cr content in plants varied from 0.74 to 4. 83 mg/kg in flowers, 1.69 to 7.85 mg/kg in leaves and 2.83 to 14.02 mg/kg in roots. Invariably, in all crops, roots accumulated higher levels of Cr than leaves and flowers. The irrigation with undiluted effluent resulted in the highest accumulation of Cr (14.0 mg/kg) in roots of *P. tuberosa* followed by *J. grandiflorum* (7.89 mg/kg) and *J. sambac* (7.82 /kg) and *N. oleander* (7.32 mg/kg). Leaves of Jathimalli appeared to have accumulated significantly higher Cr than leaves of other crops. A concentration of Cr up to 14.02 mg/kg did not exhibit any toxicity symptoms in flower crops. Large amounts of Cr were found accumulated in different parts of crops. The translocation of Cr from root to flower was found to be low in flower crops. This suggests that Cr was relatively less mobile, due mostly to its being in chromic (Cr^{6+}) form. The crops namely *J. sambac*, *J. grandiflorum* and *P. tuberosa* showed high degree of tolerance towards Cr rich-effluent irrigation, whereas, *N. oleander* was relatively sensitive to Cr-effluent.

According to Reeves *et al.* (1996) the concentration of Cr in the dry matter of the aboveground tissues as threshold to define Cr-hyper accumulator is 1000 mg/kg (0.1%). Though Cr accumulation in tested plants was far below the threshold concentration it may be noted that these plants survive at a high level of Cr contamination in soil. Therefore, such Cr-tolerant crops may be suitable for phytoremediation of Cr-contaminated soil. Evidently in the study, none of the flower crops showed any toxicity symptoms at high Cr concentration. This suggests that even at this high concentration of Cr the flower crops could grow well and therefore could safely be used for remediating the Cr-contaminated soils. In Tamil Nadu these flowers are used for worship and more by ladies as decorative in their hairstyle.

Chromium accumulation in sunflower

In the field experiment conducted with Cr-sludge, the mustard crop did not establish due to high concentration of soil Cr. However, sunflower established well and showed a high degree of tolerance towards soil Cr. The amount of Cr taken up by sunflower increased with increasing levels of Cr-sludge-Cr (Table 1). The accumulation of Cr appeared to be distributed in all the plant parts, but with more concentration in the roots. Roots accumulated the highest amount of Cr (190 mg/kg) at the highest dose of Cr-sludge application, followed by leaves (up to 9.18 mg/kg) and stem (4.23 mg/kg). Substantial amount of Cr (5.10 mg/kg) was detected in the seeds, particularly at the highest dose of sludge-Cr. Though the mustard crop was reported to accumulate large amounts of Cr our study demonstrated that this crop may not be suitable for remediating Cr-contaminated soil. The sunflower crop established very well and tolerated a high concentration of soil Cr. However, accumulation of Cr in seeds raises concern that Cr may enter into food chain and therefore it diminishes its potential for remediation.

Table 1. Accumulation of chromium in different parts of sunflower grown on soil amended with tannery sludge.

Treatments	Cr content (mg/kg)				Soil Cr * (mg/kg)
	Roots	Stem	Leaves	Seeds	
1. Control	9.84	0.60	5.10	bdl	110
2. Sludge @ 2500 mg Cr/kg soil	50.03	1.01	7.86	0.41	2576
3. Sludge @ 5000 mg Cr/kg soil	158.90	2.09	8.79	0.66	5464
4. Sludge @ 7500 mg Cr/kg soil	190.49	4.23	9.18	5.10	6843
LSD (0.05)	34.5	0.92	0.68	0.29	-

bdl = below detectable limit, * at harvest

Effect of biological wastes on chromium transformation in soil

The result of laboratory study showed that irrespective of soils, both coir pith and poultry manure markedly reduced the concentration of soluble plus exchangeable-Cr which represent toxic forms of Cr in soils (Figure 1). While 61 (clay loam) and 75 (silt clay loam) per cent reduction in the concentration of bioavailable fractions (soluble plus exchangeable) of Cr was observed with the application of coir pith, a reduction of 62.3 (clay loam) and 68 (silt clay loam) per cent was observed due to poultry manure addition.

The application of coir pith or poultry manure appeared to have reduced bioavailability of Cr in soil. This may be due to either formation of organo-chromic complexes (immobilization) or reduction of toxic, soluble Cr (VI) to non-toxic, less soluble Cr (III) in soil. The biological wastes represent a significant reservoir of electron donors for the reduction of Cr (VI) to Cr (III) (James and Bartlett 1983). During the decomposition of organic matter, compounds such as citric acid or gallic acid are formed which have the potential for chelating Cr (III) or reducing Cr (VI), and thereby reducing the toxicity of Cr (James and Bartlett 1983). Humic substances present in the biological wastes play a major role in reduction of Cr (VI). In general, it appeared that the addition of an easily degradable substrate with a low C:N ratio (poultry manure) stimulated more Cr (VI) reducers compared to high C:N ratio substrate (coir pith).

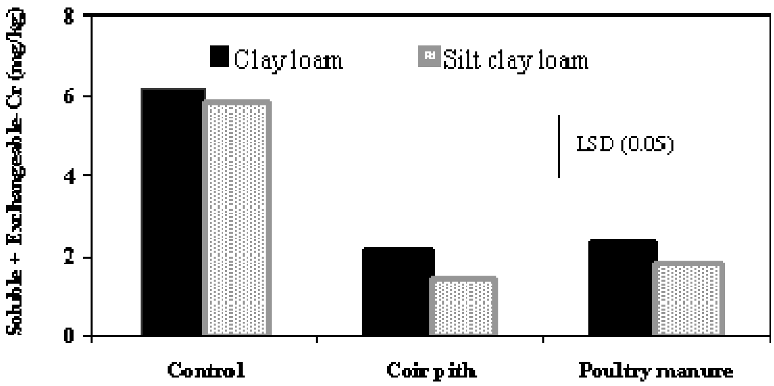

Figure 1. Effect of biological wastes on soluble and exchangeable fractions of Cr in soils.

Conclusion

The non-edible crops, like flower crops, were found suitable for phytoremediation of the Cr-contaminated soils as the entry of Cr into the food chain is largely avoided. Bioremediation, using biological wastes offers another avenue for the remediation. Addition of biological wastes and compost is known to immobilize Cr through complexation and thereby reducing the bioavailable fractions of Cr. Application of farm yard manure (FYM) or compost or biological wastes is a common practice and traditionally followed in Indian agriculture. This technology can also be exploited for the remediation of Cr-contaminated soils. Integrated approach, involving suitable chemical and biological amendments, plants and microbial strains should be required for successful remediation of Cr-contaminated soils.

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