

## Simulated In-Situ Immobilization of Heavy Metals in Selected Soils of Karnataka

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### Abstract

Chemical remediation of heavy metal infested soils is gaining importance owing to the multifaceted approach in creating ideal physical, chemical and biological conditions in the rhizosphere ensuing higher productivity. Three representative soils belonging to Alfisols, Vertisols and Ultisols spiked with 100 ppm of each Pb, Ni and Cd was treated with ameliorants like agricultural lime, potassium di-hydrogen orthophosphate (KH<sub>2</sub>PO<sub>4</sub>) and compost. Sequential extraction procedure was adopted to determine the phyto-available fraction constituting water soluble, exchangeable and carbonate bound metal with the perspective of remediation. Potassium di-hydrogen orthophosphate was the most effective chemical in attenuating Pb as indicated by the lowest phyto-available fraction in soils followed by agricultural lime and compost. For Cd, agricultural lime was superior to other amendments in all the soils. However, among the different ameliorants compost was most efficient in immobilizing Ni in all the soils.

**Keywords:** Chemical remediation; Heavy metal immobilization; phyto-available fraction

### Introduction

Heavy metals accrual in agricultural soils and subsequent deleterious effects on human health and environment is a global catastrophe a small deteriorating the quality of life. In the agricultural scenario, extensive use of chemical fertilizers, ameliorants, urban sewage-sludge and industrial effluent irrigation has aggravated the propensity of heavy metal contamination. Among the metals, Lead (Pb) Nickel (Ni) and Cadmium (Cd) are of prime concern, when present in alarming concentrations. Lead is of specific concern owing to its relative abundance besides its probable virulence to cause adverse health effects in children, while Cd in soil poses a direct contact risk to both human and ecological receptors due to its high toxicity and quick assimilation by plants [1,2]. Nickel does not form insoluble precipitates in unpolluted soils and retention for Ni is, therefore, exclusively through adsorption mechanisms. Nickel will adsorb to clays, iron and manganese oxides, and organic matter and is thus removed from the soil solution. The formation of complexes of Ni with both inorganic and organic ligands will increase Ni mobility in soils.

Assessment of metal bioavailability constitutes the fundamental aspect in amelioration of heavy metal infested soils. This approach is widely used for appraisal of metal mobility in soils by selective sequential extraction procedures [3-5]. These procedures, by virtue of increasing strength of the extractants, estimate the distribution of metals among the soluble, exchangeable, carbonate, oxide, organic and residual fraction. However, it is unwise to affirm that these representative forms extracted from soils always represent the real situation. Nonetheless, the procedure is widely accepted as first approach in assessing the likelihood of mobilization and uptake of metals from the soil. Owing to the wide spread distribution of Pb and Cd in soils resulting from anthropogenic activities and the potential risks posed by these metals, it advantageous to develop cost effective remediation strategies. Metals in contaminated soils are often present in chemical forms that exhibit varying degrees of bioavailability to human and ecological receptors. As a consequence, there has been a great concern for *in-situ* remedial strategies that render metals less bio-available, so that metal-contaminated soils seldom represent an unacceptable exposure risks. To meet this challenge, a simulation study was conducted to evaluate

the remediation process by several widely accepted soil ameliorants such as lime, zeolites, phosphates fertilizers and compost with the following objectives;

(i) To determine the influence of ameliorants on the chemical form and bioavailability of heavy metals and

(ii) To compare the efficacy of selected ameliorants as metal immobilizers in virtually contaminated soils on the temporal scale.

### Materials and Methods

#### Soils and ameliorants

Three soils viz: red soil (Alfisols) from Hanumasagar, Kustagi Taluk, Koppal District, clayey soil (Vertisols) from Ranjanagi, Mudhol Taluk, Bagalkot district and sandy clay loam (Ultisols) from Mirjan, Kumta taluk, North Canara district were selected. Air dried soil samples were analyzed for initial soil properties and the data is made available in Table 1. Three versatile ameliorants such as agricultural lime, potassium di-hydrogen orthophosphate, and compost were chosen for remediation based on the criteria of easy availability, crop compatibility, social acceptability and environmental sustainability.

#### Metal inoculation and remediation

To simulate the contaminated condition in soils, Pb, Cd and Ni were simultaneously introduced in their respective nitrates. A critical concentration of 100 mg/kg of each metal was maintained in one kg soil samples. Different ameliorants i.e., agricultural lime (@ 1 and 2%), potassium di-hydrogen orthophosphate (KH<sub>2</sub>PO<sub>4</sub> AR grade, @ 0.5 and 1%) and compost (@ 1 and 1.5%) were blended with soil separately.

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Parameters	Hanumasagara (Alfisols)	Mirjan (Ultisols)	Ranjanagi (Vertisols)
pH (1:2.5 soil:water)	6.67	5.98	7.89
EC (d S m <sup>-1</sup> )	0.525	0.056	2.112
SOC (%)	0.88	2.05	0.78
CEC [C mol (p+) kg <sup>-1</sup> ]	14.50	10.50	35.50
Nitrogen (kg ha <sup>-1</sup> )	256	378	368
P <sub>2</sub> O <sub>5</sub> (kg ha <sup>-1</sup> )	38	36	16
K <sub>2</sub> O (kg ha <sup>-1</sup> )	163	398	476
Ca [C mol (p+) kg <sup>-1</sup> ]	3.8	1.8	6.4
Mg [C mol (p+) kg <sup>-1</sup> ]	2.0	0.5	1.1
S (mg kg <sup>-1</sup> )	21	3.7	0.6
Zn (mg kg <sup>-1</sup> )	1.8	0.9	13.2
Mn (mg kg <sup>-1</sup> )	38.7	6.2	7.5
Fe (mg kg <sup>-1</sup> )	29.1	147.7	137
Cu (mg kg <sup>-1</sup> )	1.8	1.5	1.4
B (mg kg <sup>-1</sup> )	0.021	0.026	0.03
Pb (mg kg <sup>-1</sup> )	0.65	0	0.54
Ni (mg kg <sup>-1</sup> )	0.78	0.25	0.82
Cd (mg kg <sup>-1</sup> )	0.05	0.01	0.16

Table 1: Salient soil properties of the locations selected.

An absolute control with no amendment was also maintained. Each treatment was replicated thrice and adequate precaution was taken to maintain the moisture content near to field capacity so as to facilitate amelioration process. Soils spiked with metals and ameliorates were incubated at room temperature ( $\approx 25^{\circ}\text{C}$ ) for 60 days. Soil samples from each treatment were drawn after 60 days and were sequentially extracted for various forms of Pb, Cd and Ni.

### Sequential extraction

A brief summary of the most recent sequential extraction procedure developed by was adopted in the current study is highlighted in the following paragraph [6].

Two grams of soil, (100 mesh) was placed in a 50 mL polycarbonate centrifuge tube and the following extractions were performed sequentially.

- **F<sub>1</sub>**: Soil sample extracted with 20 mL of distilled water for 1 h at 20°C on a rolling table - **Water soluble (WS)** fraction
- **F<sub>2</sub>**: The residue from F<sub>1</sub> extracted with 20 mL of 1 M NH<sub>4</sub>OAC, pH 7 for 2 h at 20°C on a rolling table - **Exchangeable (EXC)** fraction
- **F<sub>3</sub>**: Residue from the F<sub>2</sub> extracted with 20 mL of 1 M NH<sub>4</sub>OAC, pH 5 for 2 h at 20°C on a rolling table - **Carbonate (CARB)** bound fraction
- **F<sub>4</sub>**: Residue from the F<sub>3</sub> extracted with 20 mL of 0.04 M hydroxylamine hydrochloride (NH<sub>2</sub>OH.HCl) in 25% acetic acid (v/v) at pH 3, reaction time 6 h in a water bath at 80°C with occasional shaking - **Oxide (OX)** bound fraction.
- **F<sub>5</sub>**: Residue from F<sub>4</sub> extracted with 15 mL of 30% H<sub>2</sub>O<sub>2</sub> (adjusted pH 2), reaction time 5.5 h in water bath at 80°C, with occasional shaking. After cooling, 5 mL of 3.2 M NH<sub>4</sub>OAC in 20% (v/v) HNO<sub>3</sub> was added; sample was shaken on a rolling table for 0.5 h at 20°C and finally diluted to 20 mL with water - **Organics (OR)** retained fraction.
- **F<sub>6</sub>**: Residue from F<sub>5</sub> fraction, extracted with 20 mL of 7 M HNO<sub>3</sub>, reaction time was 6 h in a water bath at 80°C with occasional shaking - **Residual (RES)** fraction.

Sequential extraction and analysis were done in triplicate for each sample. Metals present in different extracts were determined by atomic absorption spectrophotometer (GBC 932A).

### Results and Discussion

Sequential extraction protocol not only gives the phyto-available metal that need to be effectively bridled to contain the contamination but also provides valuable implications while selecting an appropriate ameliorant for remediation. In order to reduce the phyto-available fraction of a particular metal, the ameliorant should function in such a way to enhance the non labile pool constituting oxide bound, organically retained and residual fractions at the cost of carbonate bound, exchangeable and water soluble fractions forming labile pool. The ameliorants selected for the current study were found to work in this particular mode. The zeolites were likely to enhance the oxide bound fraction while potassium di-hydrogen orthophosphate would enhance residual fractions and similarly, the compost would enhance the organic bound fractions in the soil. However, the mode of action of agricultural lime would likely to be both as a conditioner and as an ameliorant under favorable soil reactions.

Among the different fractions extracted, invariably the water soluble and exchangeable forms are considered to be phyto-available. However, the carbonate bound fractions are also considered to be phyto-available depending on the rate of dissolution of carbonates and the soil reaction. Normally under acidic to near neutral conditions, precipitation of calcium carbonate and retention of metals by it would be a rare phenomenon. Under such conditions, it must be assumed that the extracted metal (designated as carbonate bound fraction) is derived from non-carbonate sources that are not possible to specify. Further, this fraction considered to be phyto-available and cumulated along with water soluble and exchangeable fractions to arrive at labile pool of the heavy metal.

### Cadmium amelioration

Distribution of Cd among various forms such as water soluble (F<sub>1</sub>), exchangeable (F<sub>2</sub>), carbonate (F<sub>3</sub>), oxide (F<sub>4</sub>), organic (F<sub>5</sub>) and residual (F<sub>6</sub>) fractions of Nanjangud soil is depicted in Table 2. Sequential extraction of soil samples drawn after 60 days of incubation revealed a significantly higher efficacy of ameliorants in containing the metal contamination compared to that of control. Among the different treatments involving versatile ameliorants, the lowest (46.5%) phyto-available cadmium was observed in the treatment which received agricultural lime as ameliorant. Attenuation efficacy of various ameliorants was in the order, agricultural lime > compost > KH<sub>2</sub>PO<sub>4</sub>. The maximum phyto-available Cd (62.3%) was recorded in "control" where the soil did not receive any amendment. The retention of Cd in control followed the sequence of exchangeable (29.2 mg/kg) > carbonate (28.2 mg/kg) > organic (16.7 mg/kg) > oxide (12.3 mg/kg) > residual (5.9 mg/kg) > water soluble (0.3 mg/kg) fractions. But a difference in this trend was observed in soils amended with various ameliorants. Carbonate bound fractions were higher in soil amended with lime whereas residual fractions of Cd was high in soil amended with KH<sub>2</sub>PO<sub>4</sub>. The attenuation efficiency of lime and compost were not significantly differed from each other. On the other hand lime differed significantly compared to KH<sub>2</sub>PO<sub>4</sub> in ameliorating Cd from the soil. There was no significant difference among the two levels of each ameliorant.

In general the phyto-available Cd fractions were higher in Alfisols (GKVK soils) in all the treatments compared to those of Vertisols

Treatments	Cadmium fractions							
	Hanumasagara (Alfisols)							
	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>	F <sub>4</sub>	F <sub>5</sub>	F <sub>6</sub>	Total Cd	Labile Cd (%)
Control	2.4	36.4	28.2	14.0	1.6	3.3	85.9	78.0
Lime (1.0%)	0.2	14.0	30.9	17.3	2.3	6.2	70.9	63.6
Lime (2.0%)	0.3	12.9	32.5	18.9	2.4	6.1	73.1	62.5
KH <sub>2</sub> PO <sub>4</sub> (0.5%)	1.8	22.9	26.8	13.1	2.5	6.1	73.2	70.4
KH <sub>2</sub> PO <sub>4</sub> (1.0%)	1.9	21.9	26.8	14.0	2.3	6.3	73.2	69.0
Compost (1.0%)	3.2	30.8	28.8	21.0	11.0	2.0	96.8	64.9
Compost (1.5%)	2.2	30.2	28.0	18.0	12.2	2.0	92.6	65.2
F value	**	**	**	**	**	**		**
SEm +/-	0.21	0.43	0.43	0.21		0.21		1.93
CD	0.42	0.84	0.84	0.42		0.42		5.87
Mirjan (Ultisols)								
Control	3.6	39.3	35.0	7.5	1.8	4.0	91.2	85.4
Lime (1.0%)	2.1	20.5	31.5	13.6	2.5	4.2	74.5	72.7
Lime (2.0%)	1.9	18.5	30.3	15.8	2.9	4.7	74.0	68.4
KH <sub>2</sub> PO <sub>4</sub> (0.5%)	0.6	31.0	29.1	9.6	1.9	5.2	77.4	78.5
KH <sub>2</sub> PO <sub>4</sub> (1.0%)	0.9	30.7	27.0	11.0	1.65	5.8	77.0	76.0
Compost (1.0%)	2.6	35.3	28.9	9.0	11.5	2.8	90.1	74.2
Compost (1.5%)	1.9	34.3	28.0	7.8	12.1	3.2	87.3	73.6
F value	**	**	**	**	**	**		**
SEm +/-	0.21	0.43	0.43	0.21	0.21	0.21		2.09
CD	0.42	0.84	0.84	0.42	0.42	0.42		6.35
Ranjanagi (Vertisols)								
Control	0.3	29.2	28.2	12.3	16.7	5.9	92.6	62.3
Lime (1.0%)	0.1	11.3	27.1	15.6	15.3	10.8	80.3	48.0
Lime (2.0%)	0.2	10.5	28.1	18.2	15.8	10.6	83.4	46.5
KH <sub>2</sub> PO <sub>4</sub> (0.5%)	0.5	21.5	23.1	13.2	13.7	11.9	83.9	53.3
KH <sub>2</sub> PO <sub>4</sub> (1.0%)	0.4	22.9	20.5	17.9	13.8	11.0	83.5	52.5
Compost (1.0%)	0.2	20.7	22.1	14.3	16.9	10.6	84.8	50.7
Compost (1.5%)	0.3	20.2	24.5	15.0	18.9	10.6	89.4	50.3
F value	**	**	**	**	**	**		**
SEm +/-	0.02	0.65	0.43	0.43	0.43	0.43		1.68
CD	0.04	1.26	0.84	0.84	0.84	0.84		5.11

**Table 2:** Different Cd fractions under versatile ameliorants.

(Nanjangud soils). The data obtained from the sequential extraction revealed that the retention of Cd in various fractions followed the sequence of exchangeable (36.4 mg/kg) > carbonate (28.2 mg/kg) > oxide (14.0 mg/kg) > residual (3.3 mg/kg) > organic (1.6 mg/kg) > water soluble (0.3 mg/kg) in the soil under the Control, which did not receive any amendment. The lowest (62.5%) phyto-available Cd was observed in the treatment which received 2% agricultural lime as ameliorant followed by 1% agricultural lime (63.9%) < 1.5% compost=1% compost (65.8%) < 0.5% KH<sub>2</sub>PO<sub>4</sub> (70.4%) < 1% KH<sub>2</sub>PO<sub>4</sub>. Highest (78.0%) phyto-available cadmium was recorded in the treatment (control) not receiving any sort of ameliorant. The different levels of each ameliorant did not differ significantly in amelioration. Similarly the attenuation capacity of agricultural lime was on par with compost (P=0.05). Lime and compost differs significantly from KH<sub>2</sub>PO<sub>4</sub> in Cd attenuation of this soil.

The different fractions of Cd extracted from the Ultisols (Brahmavara soil) revealed that compared to other two soils much of the Cd retained in the mobile fractions even with the application of various ameliorants. However, the efficacy of 2% lime was significantly higher than other two amendments in reducing the mobile fractions of Cd. As with any

remediation, the overall objective of chemical remediation approach adopted in the current study is to create a final solution that assures protection of human health and the environment. With scrupulous and scientific adoption of remediation techniques, the possibilities of transport of contaminants from the polluted soil to the agricultural products meant for human consumption could be effectively mitigated. The mobility of Cd is more in Ultisols followed by Alfisols and Vertisols. In all the soils lime was more efficient in ameliorating Cd than all other elements. Even with the ameliorants the mobile fractions of Cd has not reduced much. The mobile fractions of Cd were low in black soil in all the treatments. Cadmium immobilization with lime may be attributed to the metal hydrolysis and/or co-precipitation with applied lime in soils. Consequently the phyto-availability of heavy metals would be drastically reduced [4,7]. Similar results where lime has been found to be effective at reducing plant uptake of zinc, but mixed results have been reported for plant uptake of cadmium [8,9].

Compost was more efficient than KH<sub>2</sub>PO<sub>4</sub> in immobilizing Cd from all the soils. As far as Cd and Ni attenuation with compost is concerned, current results corroborated with the works of who studied the remediation of Cd pollution in soils by different amendments

[10,11] demonstrated that lime-stabilized bio-solids were capable of immobilizing Zn in smelter-impacted soils and reduced the eco-toxicity of the soils to earthworms. This suggests that the organic amendment in combination with lime can reduce the phyto-availability of heavy metals effectively reports the beneficial effect of application of spent mushroom compost (SMC) in reducing the metal contamination from the Pb-Zn contaminated site [12]. The results of the present study are in agreement with these findings.

### Lead amelioration

The distribution of Pb in various fractions as observed in all the three soils is presented in the Table 3. In the Vertisols, unlike Cd much of the Pb remained in the residual fraction even without the amendment. The various fractions in the control were in the order; residual (40.6 mg/kg) > oxide bound (25.3 mg/kg) > org (18.7 mg/kg) > carbonate bound (8.6 mg/kg) > exchangeable (1.1 mg/kg) > water soluble (0.7 mg/kg). The amendment treated soil also followed the same trend as that of control; however, the attenuating efficiency of various ameliorants followed the order of 1%  $\text{KH}_2\text{PO}_4$  > 1.5% compost > 0.5%  $\text{KH}_2\text{PO}_4$  > 1% compost > 2% lime > 1% lime. The mobile fraction of

Pb in the lime amended soil did not show a significant decrease from that of control.

Compared to the Vertisols, mobile fractions of Pb were higher in the Alfisols. The sequence observed in this soil was residual (34.9 mg/kg) > oxide bound (23.9 mg/kg) > carbonate bound (21.8 mg/kg) > organic bound (14.2 mg/kg) > exchangeable (3.6 mg/kg) > water soluble. The treatments with various ameliorants reduced both the exchangeable and carbonate bound fractions and there was an increase in the oxide bound fractions and the highest residual fraction was noticed in the treatment with  $\text{KH}_2\text{PO}_4$ . The mobile fractions of Pb observed in all the ameliorant treated soils were significantly lower than that of control. The lowest (14.2%) mobile fraction of Pb was observed in the treatment with 1%  $\text{KH}_2\text{PO}_4$  followed by 0.5%  $\text{KH}_2\text{PO}_4$  (15.5%) < 2% lime (18.6%) < 1% lime=1.5% compost (19.5%). The efficacy of 1.0%  $\text{KH}_2\text{PO}_4$  in ameliorating Pb was significantly higher than all other treatments.

Among all three soils the highest mobile fraction of Pb was observed in Ultisols. Sequential distribution of Pb in this soil was residual (35.0 mg/kg) > oxide bound (24.0 mg/kg) > carbonate bound (22.0 mg/kg) > organic bound (12.7 mg/kg) > exchangeable (3.9 mg/kg)

Treatments	Nickel fractions							
	Hanumasagara (Alfisols)							
	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>	F <sub>4</sub>	F <sub>5</sub>	F <sub>6</sub>	Total Ni	Labile Ni (%)
Control	0.0	25.7	16.2	27.6	18.8	4.8	93.2	45.0
Lime (1.0 %)	0.0	14.2	12.5	26.2	21.9	12.2	86.9	34.4
Lime (2.0 %)	0.0	13.6	15.7	26.5	21.2	11.9	88.9	29.3
$\text{KH}_2\text{PO}_4$ (0.5%)	0.3	21.2	12.5	25.7	19.0	17.8	96.5	35.2
$\text{KH}_2\text{PO}_4$ (1.0%)	0.2	21.0	12.4	24.5	20.8	18.1	97.0	34.7
Compost (1.0%)	0.1	17.1	14.2	22.4	25.7	10.7	90.2	34.8
Compost (1.5%)	0.0	17.0	13.6	24.0	26.0	10.8	91.4	33.5
F value	**	**	**	**	**	**		**
SEm +/-	---	0.12	0.43	0.43	0.43	0.43		1.76
CD	---	0.24	0.84	0.84	0.84	0.84		5.33
Mirjan (Ultisols)								
Control	0.0	26.9	17.6	28.8	15.5	5.1	93.9	47.3
Lime (1.0 %)	0.0	12.6	19.2	27.8	14.2	14.7	88.5	35.9
Lime (2.0 %)	0.0	10.8	18.6	25.5	17.4	12.6	84.8	34.7
$\text{KH}_2\text{PO}_4$ (0.5%)	0.1	14.8	17.8	25.0	12.9	18.0	88.5	36.9
$\text{KH}_2\text{PO}_4$ (1.0%)	0.0	14.2	16.9	25.3	13.2	18.0	87.7	35.5
Compost (1.0%)	0.2	8.8	17.9	22.8	18.9	19.0	87.6	30.7
Compost (1.5%)	0.0	7.1	17.5	22.1	23.7	20.0	90.4	27.2
F value	**	**	**	**	**	**		**
SEm +/-	---	0.43	0.43	0.43	0.43	0.12		1.35
CD	---	0.84	0.84	0.84	0.84	0.24		4.1
Ranjanagi (Vertisols)								
Control	0.0	10.0	32.2	13.7	31.0	8.7	95.6	44.2
Lime (1.0 %)	0.0	6.6	15.2	24.9	23.3	25.1	95.0	22.8
Lime (2.0 %)	0.0	4.5	17.9	29.2	18.4	29.0	99.0	22.6
$\text{KH}_2\text{PO}_4$ (0.5%)	0.0	13.2	10.5	32.6	12.6	26.8	95.7	24.7
$\text{KH}_2\text{PO}_4$ (1.0%)	0.0	13.3	9.3	26.5	23.4	22.7	95.3	23.7
Compost (1.0%)	0.0	6.1	16.0	21.2	27.8	26.3	97.3	22.7
Compost (1.5%)	0.0	5.5	14.6	21.0	28.7	26.6	96.3	20.8
F value	**	**	**	**	**	**		**
SEm +/-	---	0.43	0.43	0.21	0.43	0.43		1.72
CD	---	0.84	0.84	0.41	0.84	0.84		5.23

Table 3: Different Pb fractions under versatile ameliorants.

> water soluble. The lowest mobile fraction of Pb was observed in the treatment with 1%  $\text{KH}_2\text{PO}_4$  followed by that of compost and lime. All the amendments could significantly reduce the mobile fractions of Pb compared to that of control. There was no significant difference among various ameliorants in their attenuation efficacy.

Compared to that of Cd, mobile fractions of Pb were low in all the soils; however, mobile Pb was more in Ultisols. Lead retention in soil mainly attributed to the ion exchange or specific sorption on silicates, metal oxides and hydroxides, and organic matter [7]. Among the different ameliorants  $\text{KH}_2\text{PO}_4$  was most efficient in immobilizing Pb from all the soils. Phosphate has long been known to be effective at stabilizing Pb, as demonstrated by [13]. The concept is to induce the formation of highly insoluble Pb phosphate minerals that have a low bioavailability and mobility and are stable under a variety of environmental conditions (Ruby et al. 1994). Phosphate salts are capable of immobilizing Pb in soils due to the formation of low soluble Pb orthophosphate complexes [13-15].

### Nickel amelioration

The order of existence of various fractions of Ni as observed by the sequential extraction method is depicted in the Table 4. In the Vertisols, the hierarchy of various fractions in the control was carbonates (32.2 mg/kg) > organic (31.0 mg/kg) > oxide bound (13.2 mg/kg) > exchangeable (10.0 mg/kg) > residual (8.7 mg/kg). All the amendments could significantly reduce the mobile fractions of Ni compared to that of control. The lowest mobile fraction was observed in the soil treated with 1.5% compost but the difference in the attenuating efficiency of various ameliorants was not significant. The differential allocation of various fractions of Ni in Alfisols was oxide bound > exchangeable > organic bound > carbonate bound > residual > water soluble. All the ameliorants could significantly reduce the mobile pool of Ni compared to that of control. A significantly higher efficiency was observed for 2% agricultural lime in attenuating Ni from this soil. However, a higher amount of Ni was observed in Ultisols compared to other two soils. The order of existence of different fractions in the control was observed as oxide bound > exchangeable > carbonate bound > organic bound >

Treatments	Nickel fractions							
	Hanumasagara (Alfisols)							
	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>	F <sub>4</sub>	F <sub>5</sub>	F <sub>6</sub>	Total Ni	Labile Ni (%)
Control	0.0	25.7	16.2	27.6	18.8	4.8	93.2	45.0
Lime (1.0 %)	0.0	14.2	12.5	26.2	21.9	12.2	86.9	34.4
Lime (2.0 %)	0.0	13.6	15.7	26.5	21.2	11.9	88.9	29.3
$\text{KH}_2\text{PO}_4$ (0.5%)	0.3	21.2	12.5	25.7	19.0	17.8	96.5	35.2
$\text{KH}_2\text{PO}_4$ (1.0%)	0.2	21.0	12.4	24.5	20.8	18.1	97.0	34.7
Compost (1.0%)	0.1	17.1	14.2	22.4	25.7	10.7	90.2	34.8
Compost (1.5%)	0.0	17.0	13.6	24.0	26.0	10.8	91.4	33.5
F value	**	**	**	**	**	**		**
SEm +/-	---	0.12	0.43	0.43	0.43	0.43		1.76
CD	---	0.24	0.84	0.84	0.84	0.84		5.33
Mirjan (Ultisols)								
Control	0.0	26.9	17.6	28.8	15.5	5.1	93.9	47.3
Lime (1.0 %)	0.0	12.6	19.2	27.8	14.2	14.7	88.5	35.9
Lime (2.0 %)	0.0	10.8	18.6	25.5	17.4	12.6	84.8	34.7
$\text{KH}_2\text{PO}_4$ (0.5%)	0.1	14.8	17.8	25.0	12.9	18.0	88.5	36.9
$\text{KH}_2\text{PO}_4$ (1.0%)	0.0	14.2	16.9	25.3	13.2	18.0	87.7	35.5
Compost (1.0%)	0.2	8.8	17.9	22.8	18.9	19.0	87.6	30.7
Compost (1.5%)	0.0	7.1	17.5	22.1	23.7	20.0	90.4	27.2
F value	**	**	**	**	**	**		**
SEm +/-	---	0.43	0.43	0.43	0.43	0.12		1.35
CD	---	0.84	0.84	0.84	0.84	0.24		4.1
Ranjanagi (Vertisols)								
Control	0.0	10.0	32.2	13.7	31.0	8.7	95.6	44.2
Lime (1.0 %)	0.0	6.6	15.2	24.9	23.3	25.1	95.0	22.8
Lime (2.0 %)	0.0	4.5	17.9	29.2	18.4	29.0	99.0	22.6
$\text{KH}_2\text{PO}_4$ (0.5%)	0.0	13.2	10.5	32.6	12.6	26.8	95.7	24.7
$\text{KH}_2\text{PO}_4$ (1.0%)	0.0	13.3	9.3	26.5	23.4	22.7	95.3	23.7
Compost (1.0%)	0.0	6.1	16.0	21.2	27.8	26.3	97.3	22.7
Compost (1.5%)	0.0	5.5	14.6	21.0	28.7	26.6	96.3	20.8
F value	**	**	**	**	**	**		**
SEm +/-	---	0.43	0.43	0.21	0.43	0.43		1.72
CD	---	0.84	0.84	0.41	0.84	0.84		5.23

Table 4: Different Ni fractions under versatile ameliorants.

residual > water soluble. The mobile pool of Ni was significantly lower in the amendment added soil than that of control. Both 1% and 1.5% compost were efficient and differed significantly in bridling mobile Ni compared to other ameliorants.

The mobile fractions of Ni observed in all the soils were in between that of Pb and Cd. Like Pb and Cd mobile fractions of Ni were also more in Ultisols. Among the different ameliorants compost was most efficient in immobilizing Ni in all the soils. The reduced availability of Ni in the organic matter enriched soil was due to the binding of Ni by the organic matter. The application of organic matter provides more sorption sites for heavy metal sorption [9].

## Summary

Among the three metals phyto-available fractions of Cd were more than that of Ni as well as Pb. Similarly, the phyto-available fractions of all the elements were high in Ultisols followed by Alfisols and Vertisols. Among the ameliorants, potassium di-hydrogen orthophosphate was the most effective in attenuating Pb in all the three soils. On the contrary, lime was superior to all other amendments in bridling Cd while in Ni, compost and lime were found equally superior in reducing the mobile fractions.

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