Effect of Metal Pickling and Electroplating Industrial Sludge-Borne Heavy Metals on Wheat (*Triticum aesativum*) Seedling Growth

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Abstract:

A pot culture study has been undertaken to evaluate the effect of rolling and pickling industrial sludge amendments on growth response and bioaccumulation of heavy metal in wheat seedlings. Processed acidic waste was first treated with three doses of lime (0, 0.5 and 1%) and then mixed with two soils in different ratios (0, 10 and 20%). Samples were filled in earthen pots (2Kg/pot) one week before planting and seven days old wheat seedlings (3 per pot) were transplanted in these pots and pots were kept in glass house. Temperature of glass house was maintained at 22±2^{0}C and moisture contained at 50% of water holding capacity.

DTPA extractable heavy metals and metals in seedlings increased with increasing doses of industrial sludge amendments. Biomass and growth has been also found to increase with increasing rate of sludge. Lime enhanced the biomass and reduced the heavy metal concentrations. Although 20% treatments in both soils showed a significant enhancement in shoot length but metals like Pb was found beyond permissible limit. The heavy metal in wheat seedlings follow the trend Zn>Pb>Cu>Cd. Lime has a negative correlation with availability and uptake of heavy metals. Results showed that application of lime treated industrial sludge to soil could be useful in order to increase crop growth in the glass house. [Nature and Science 2010;8(3):1-8]. (ISSN: 1545-0740).

Key words: pot culture, industrial waste, bioaccumulation, DTPA extractable metals.

1. Introduction:

The concern about heavy metals is that they are non-biodegradable and may therefore accumulate in the environment. Thus, one of the development challenges facing this decade is how to achieve a cost effective and environmentally sound strategies to deal with the global waste crisis (Alloway and Aryes, 1997). The crisis has also threatened the assimilative and carrying capacity of the earth, which is our life support system.

Not only the developed countries but developing countries like India is also facing the problem of huge quantity of solid waste releasing per day in environment. Some of them like industrial and hospital waste come under hazardous and some time it is also carcinogenic due to its composition. The National Capital Territory of Delhi, India, with a population more than 14 million, covering an area of 1483 sq Km has emerged as one of the biggest centers of small-scale industries in the country. It has 21 industrial areas, generating an enormous quantity of industrial waste per day (Office of the Commissioner of Industries, Delhi, 1996). Disposal of this perpetual quantity of waste remains a major problem. Land disposal of waste is a very old method because organic wastes obtained from different sources (Municipal, Industrial, or zoo technical) has two advantages: it avoids accumulation of wastes in the environment and it provides organic matter and nutrients for soil (Narwal et al., 1983).

Although the nutrient content of wastes makes them attractive as fertilizers, land application of many industrial and sewage sludge are constrained by the presence of heavy metals, hazardous organic chemicals, salts, and extreme pH (Cameron et al., 1997). On the other hand land application of industrial/sewage sludge is the potential source for metals accumulation in crops, which in turn will transfer to food chain posing a potential health hazard to human being (Cameron et al., 1997). Investigations illustrate the benefits of sludge are extremely important, since there is still a general reluctance among agriculturists to recognize the economic value of the sludge in order to improve the soil organic status without contaminating the environment (Korentejar, 1991). From most of the research works it is proved that the industrial and municipal waste have high amount of N and P (Mohammad and Battikhi, 1997). So, there is an increasing interest in the agricultural application of sludge due to the possibility of recycling valuable components: N, P and other plant nutrients (Gupta and Sinha, 2007).

Soil is a vital resource for sustaining two human needs of quality food supply and quality environment. Plants grown on a land polluted with municipal, domestic or industrial wastes can absorb heavy metals in the form of mobile ions present in the soil solution through their roots or through foliar absorption. These absorbed metals get bioaccumulated in the roots, stems, fruits, grains and leaves of plants (Fatoki, 2000). By considering above facts this study was proposed to assess the effect of industrial sludge on growth and yield of wheat seedling under glasshouse conditions. Heavy metal concentrations were determined in the sludge and soil to characterize plant soil interactions of the sludge borne heavy metals on different soil types. In the best of our knowledge a very few study have been undertaken for the phytoremediation of any type of industrial sludge, hence, it is the first attempt in this field.

2. Materials and methods:

2.1. Collection of samples and preparation

Industrial sludge samples from metal finishing industries were collected from Wazirpur industrial area of Delhi. This is situated northwest part of Delhi, covering an area of 210 acre, is a big source of solid wastes generation, producing more than 30% of total solid waste of Delhi (Office of the Commissioner of Industries, Delhi, 1996). We collected 30 waste samples from 3 blocks of study site in three seasons i.e. Monsoon, Winter and Summer.

Waste samples stored in a transparent poly bags and fresh samples were used to measure pH, Electrical Conductivity, Moisture Content (%) and Water Holding Capacity (WHC). Then processed samples were subjected to a proper mixing to form a single representative sample. Analyses were done for the potential bioavailable heavy metals (Lindsay and Norvell, 1978) and total heavy metal concentration (EPA 3050 method). To neutralize the acidity of waste it was treated with lime in different ratios (0, 0.5, and 1%).

Two different soil types were collected from New Delhi, India. The site 1 soil (S1) is sandy loamy farmland soil while site 2 (S2) is a sandy nursery soil. The lime treated sludge samples were mixed to soils in 3 different ratios (0, 10 and 20%) and used to fill earthen pots (2Kg/pot) one week before planting. Wheat *(*HD1553*)* seeds were collected from National Seed Corporation, New Delhi (NSC) and seven days old seedlings were transplanted, 3 per pot, into pots. The experiment was performed under glasshouse conditions.

2.2 Soil and plant analysis

Soil samples were analyzed at two different times during the experiment: at initial stage of experiment and after 28 days of growth. The soil samples, which were analyzed at the end of experiment, consisted of soil sample and wheat seedling roots. Samples were analyzed for heavy metal content (available and total heavy metal) of four metals (Pb, Cd, Zn and Cu).

Wheat seedlings were allowed to grow for 28 days in the glass house before the harvesting. The above-ground parts were separated from the roots, which were left in the soil for analysis. Plant materials were washed several times with tap water and then with ionized water. Now foliages were dried at 60^0C to determine its dry mass. Above ground plant samples were analyzed for total heavy metal content (Allen et al., 1986).

2.3 Translocation factor (*f*)

The accumulation of metals in the plant parts when taken up from soil was determined as *f* factor, also known as transfer coefficient (Smith, 1996).

2.4 Statistical analysis:

All the data were analyzed using one way ANOVA test using GPIS software (1.13) (Graphpad, California, USA) and different correlations and regressions has been done for statistical analysis of data by using SPSS version 11.5.

3. Results and discussion:

3.1 General properties of waste and soils:

The dried sludge had a solid content of 93.5%. All the parameters like electrical conductivity, organic carbon and cation exchange capacity were more in industrial sludge in comparison to soils (data not shown), except pH i.e. very low in waste (3.05±0.03). Heavy metals were (Zn, Pb, Cu, and Cd) analyzed and compared to current heavy metal guidelines (USEPA, 1993) were depicted in Table 1. The heavy metal guidelines exceeded for Pb (440±0.36 mg/Kg) only. A high Zn, Cu and Cd concentration in this waste is because more than 70% industries are involved in metal pickling and electroplating. Giri and Bhattacharyya, (1999) also reported that industrial waste from metal finishing industries have a high quantity of macro and micronutrients as well as heavy metals, which is consistent with this study. In our study total and available heavy metals in waste have following trend; Zn>Pb>Cu>Cd.

Soil pH is one of the major factors controlling the availability of heavy metal in soils (Brady, 2000). Background pH values of the site1 and site 2 soils were 8.76±0.03 and 8.22±0.04 respectively (data not shown). In control soils total metal concentrations were more in site1 soil than site 2 soil and showed the following trend; Zn>Pb>Cu>Cd. For high concentration of heavy metals in site 1 soil is might be due to its location. It is situated within 5Km radius of Badarpur Thermal Power Station (BTPS) and it is assumed that fly ash and other pollutant are likely to contaminate this soil. Analytical results indicated that in control soils values of all heavy metals were below the literature levels of a typical soil except Pb (19ppm).

3.2 Heavy metal accumulation and translocation in wheat seedlings:

For both soils, total heavy metal as well as DTPA-extractable heavy metal contents increased linearly as the waste percentage increased in soil (Fig1). Rappaport et al., (1988) also reported that amount of DTPA-extractable Cd, Cu, Ni, Mn, and Zn increased linearly with rate of sludge application. Due to the acidic nature of waste, its amendment increased the pH and decreased the availability of metals as pH is also one of the soil factors that governs the availability of metals in soils (Norwal et al., 1983). Tables 2 showing that availability of all studied DTPA-extractable metals were also depend on soil pH, OC and CEC.

In the present study, correlation analysis (r) was performed in order to investigate the relationship between the DTPA extractable metals in different amendments of the electroplating sludge and the total accumulation of metal in the plant parts (Table 3). It was observed that all the metals in plants were highly correlated with the available metals of the soil at the end of experiment, except, Zn and Pb. Many other researchers were also reported the same and were consistent with this study (Karcka, 2004).

Copper is one of the most important essential elements for plants and animals (Alloway, 1995). Fig 1A showed that guideline limits of 25ppm for Cu doesn't exceeded in any soil. Effect of industrial amendments and lime were found to follow the similar trend like Zn. Cu concentrations in seedling tissue did not reach phytotoxic levels 20-100ppm (Smith, 1996) in any treatments (Fig 2A). The normal transfer coefficient for Cu in plants is between 0.01-0.1 (Kloke et al., 1984) and it consisted with this study (0.03-0.12). So, Cu in this study is not responsible for any type of phytotoxicity.

In normal situation Zn acts as micronutrient but at higher concentration it becomes phytotoxic (Alloway, 1995). It is evident from the Fig 1B that Zn concentrations were above the guideline limits after the waste amendments in both soils. The value within the bar showed the availability of metal as the percent of total metal in soils. Waste amendments increased the Zn concentration in all treatments (McBride et al., 2003). But the increment was more in site 1 soil than site 2 soil due to background level in soils. Lime amendments significantly ($P<0.05$) reduced the availability of DTPA extractable metals in all treatments as compared to its counterpart without lime treatment. This can be explained by the increase in soil pH following lime amendment, and the reduced solubility of these metals in soil at high pH. Wong et al., (2001) and Vulkan et al., (2000) also reported that lime amendments reduced the availability of metals in amended soils.

Fig 2B showed the Zn concentration in wheat seedling tissue after the 28 days of growth and the value within the bar showed the transfer coefficient (*f*). Zn concentration didn't reach phytotoxic levels (100-400ppm) in any treatment (Fifield and Hannies, 2002). Normal transfer coefficient (*f*) of Zn for the plants was found 1-10 (Kloke et al., 1984). But in our study it was below this value and it ranges 0.25-0.57. As evident from the Fig 2A transfer coefficient was also more in site 1 soil than site 2 soil and lime have negative effect on transfer coefficient. The higher Zn concentration of site 1 soil transfers more Zn and thus uptake of Zn by seedlings.

Cadmium is an important heavy metal pollutant, the presence of which in agricultural soils and crops is of great concerns. Naturally occurring Cd concentration in soils ranges from 0.001-3ppm (Alloway, 1995). Waste amendment also increased the total and bioavailable Cd in the soils, which supports the study of McBride, (2003). Cd availability to crops is affected by: soil pH, CEC, soil texture, crop species and interrelationship of Cd with other elements in soil (Table 3). In contrary Tsadilas (1995) reported that available Cd is only pH dependent and independent on other physiological properties of soil like CEC, OC etc.

Cd level decreased significantly in the soil types over the 28 days due to accumulation of Cd in plant tissue (Hooda et al., 1997). We observed that most of the Cd is retained by the roots and not transferred to the shoots which show that wheat is an accumulator for metals (Fig 2C). The uptake of Cd into the wheat seedling did not reach the phytotoxic levels of (5-30ppm) except seedlings from 20% waste amended (without lime) site 1 soil. The plant transfer coefficient for Cd in plants tissue is 1-10 (Kloke et al., 1984). So for transfer coefficient all the plants have less value (0.09-0.30) than this limits and transfer coefficient. Lime reduced the uptake of Cd as well as transfer coefficient (*f*).

Lead, being the zootoxic metal, needs to be monitored in plants parts used by humans and animals (Alloway, 1995). Lead occurs naturally in all plants. In the environment, lead exists almost entirely in inorganic form. Significant reductions were observed in Pb concentration for both soils during this study. Fig 1D showed that the total and bioavailable Pb concentration in both control and waste amended soils. Lead concentration of both soils were below the permissible limits (750-1200µg/g) set by the USEPA, 1993. Up to seedling stage not much variation obtained in this study, which showed that Pb is not much more mobile in soil system, which was consistent with the findings of Kabata-Pendias and Pendias, (1991); and Valtcho et al., (2004).

Uptake of the Pb in the seedling was low and did not reach the phytotoxic level of 30-300ppm (Alloway, 1995) as depicted in Fig 2D. A normal plant transfer coefficient (*f*) value for Pb in wheat seedling is between 0.01-0.1 (Kloke et al., 1984), therefore the transfer coefficient for both soils was high only in without lime treated waste amendments. Lime reduces the transfer coefficient as well as uptake of the Pb by wheat seedlings. Higher transfer coefficient and uptake of Pb in the seedling tissue occurred in site1 soil due to its background level.

3.3 Growth:

The shoot length, fresh mass and dry weight of wheat seedlings were depicted in table 4. Industrial sludge amendments increased plant growth significantly as compared to the control ones. But 10% waste amendments were found more significant over 20% amendments in both soils. This emphasized the potential short-term beneficial effects of sludge to soils as an organic soil conditioner. From these findings it evident that soil amendment above 10% is not good because it also provides heavy metals to plants and growth become retarded. Plants from site 1 soil exhibited a good growth compare to its counterpart due to its background level.

Lime amendment demonstrated a positive effect on plants growth at each sludge amendment level, which was likely due to increased in pH and reduction in the availability of heavy metals. Most agricultural crops grow well when soil pH is between 6.0-7.0, because nutrients are more available at pH about 6.5 (Soummare et al., 2003). However heavy metal behavior still differs individually and other soil physical properties, like textures might play an important role in heavy metal behavior in soils (Maclean et al., 1987).

4. Conclusion:

In this study it was observed that the industrial sludge from metal finishing industries was highly acidic and had a high amount of heavy metals. Lime had the positive effect and reduced the availability, uptake as well as transfer coefficient in all treatments. The industrial sludge affected the yield of the wheat seedlings positively compared with control plants. However no phytotoxic effects could be proven, because phytotoxic levels were not exceeding in wheat seedling tissues. Although it was a pot culture study and could not draw the actual picture but may be used as baseline data for further analysis. For land application of sludge, needs to possibly take in to consideration the environmental conditions, crop plated, soil type and sludge type. This might lead to the unrestricted industrial sludge on agricultural land, causing a decrease in technological costs for wastewater treatments plants (and subsequent financial profit) to eliminate heavy metals in sludge.

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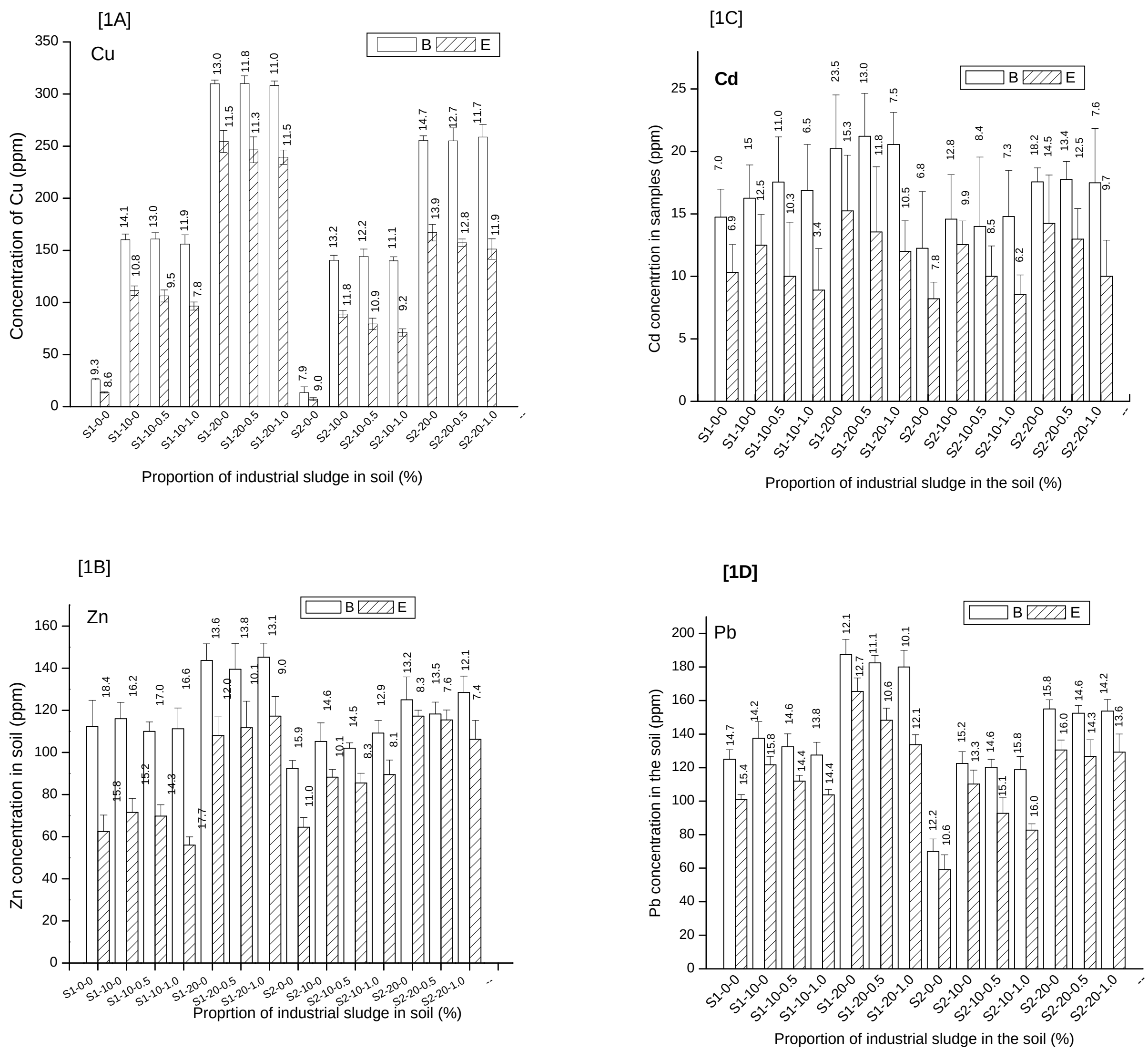

Figure 1: Showing the metals concentration (ppm) in control and industrial sludge amended soils at beginning (B) and (E) of experiment. Values between vertical bars indicate percentages availability of metals. Values are the mean of three data with SD (±)

Notation; e.g.S1/S2$_1$-10$_2$- 0.5%$_3$: 1-Site1/2 soil; 2-percentage of the waste; 3-percentage of lime treatment

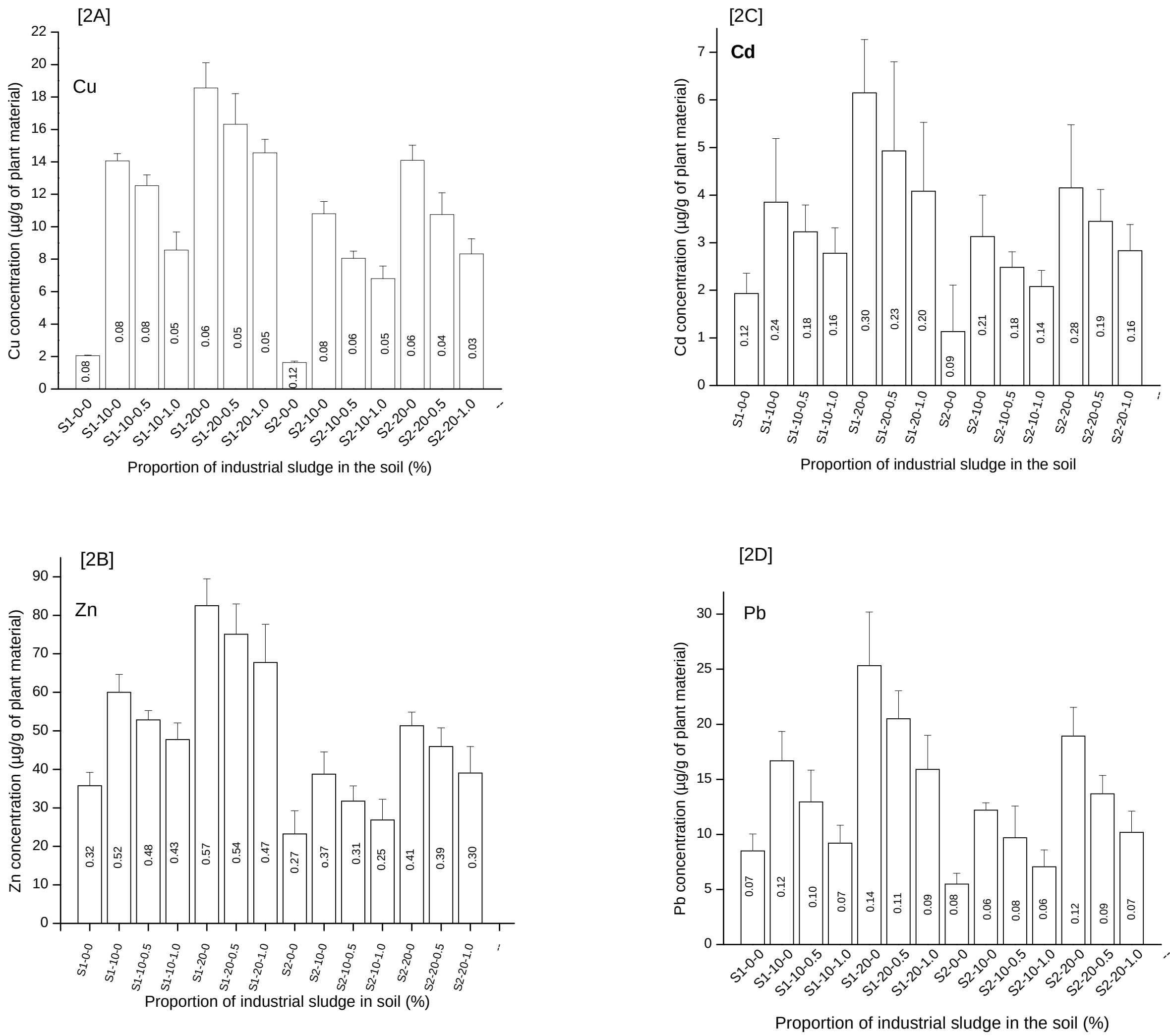

Figure 2: showing the total metal concentration (µg/g of plant material) in wheat seedling tissues in all treatments. f factor indicated within vertical bars. Values between vertical bars indicate percentages availability of metals. Values are the mean of three data with SD (±)
Notation; e.g.S1/S2$_1$-10$_2$- 0.5%$_3$: 1-Site ½ soil; 2-percentage of the waste; 3-percentage of lime treatment

Table 1: Heavy Metals content of Industrial sludge and soils (mg/Kg) on dry wt. basis with std deviation

Metals	Total metal content					Extractable metal content		
	Industrial Sludge	Limits values in sludge* (mg/Kg)	Soil Site1	Soil Site2	Limits values in soil* (mg/Kg)	Industrial Sludge	Soil Site1	Soil Site2
Zn	1290±0.52	**2800**	42.25±0.58	22.25±0.48	**130-200**	44.25±0.27	10.63±0.02	4.69±0.02
Cu	410±0.44	**1500**	25.75±0.12	13.48±0.15	**60-100**	31.72±0.56	2.40±0.02	1.06±0.01
Cd	30.16±0.21	**30**	4.21±0.12	2.25±0.11	**1-3**	1.15±0.01	1.03±0.06	0.83±0.02
Pb	440±0.36	**300**	65±0.21	50±0.39	**19**	56.12±0.11	8.34±0.12	5.84±0.06

*C.E.C. (1986)

Table 2: Linear regression coefficient values* (R^2) between soil DTPA-extractable metals and pH, organic carbon, CEC in soil at harvesting stage						
Metals	R^2 value in Site 1 soil			R^2 value in Site 2 soil		
	pH	OC	CEC	pH	OC	CEC
Cu	0.72	0.65	0.53	0.85	0.89	0.94
Zn	0.09	0.08	0.10	0.09	0.06	0.02
Cd	0.96	0.91	0.80	0.81	0.70	0.82
Pb	0.25	0.15	0.05	0.39	0.14	0.09

*at 0.05 level of significance

Table 3 Correlation coefficients (r) between soil available metals at the end of experiment and metal concentrations in seedlings of wheat plants		
Metals	Site 1 Soil	Site 2 Soil
Cu	0.90	0.81
Zn	0.86	0.78
Cd	0.81	0.83
Pb	0.86	0.76

*at 0.05 level of significance

Table 4: Average shoot length, fresh and dry mass after 28d of growth			
Treatments	**Shoot length (cm)**	**Fresh mass (g/plant)**	**Dry mass (g/plant)**
S1-0-0	28.3	10.2	1.02
S1-10-0	35.2	13.2	1.22
S1-10-0.5	37.7^{c}	15.2	1.45^{ac}
S1-10-1.0	40.1^{b}	17.5	1.61^{a}
S1-20-0	39.8^{b}	14.2	1.31^{b}
S1-20-0.5	41.3^{a}	18.5^{c}	1.68^{ac}
S1-20-1.0	44.5^{ac}	21.2^{bc}	1.98^{ab}
S2-0-0	25.2	9.8	1.0
S2-10-0	30.3	12.3	1.14
S2-10-0.5	33.5	13.2	1.28^{ac}
S2-10-1.0	35.8^{c}	15.6	1.34^{a}
S2-20-0	36.8^{b}	15.2	1.35^{b}
S2-20-0.5	39.1^{b}	16.9^{c}	1.45^{ac}
S2-20-1.0	42.5^{ab}	18.8^{bc}	1.69^{ab}

Notation; e.g. $S1/S2_1$-10_2- $0.5\%_3$: 1-Site1/2 soil; 2-percentage of the waste; 3-percentage of lime treatment. [a] $p<0.001$; [b] $p<0.01$; [c] $p<0.05$ compared to control.