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# Chemical Immobilization of Lead (Pb) in Long Term Sewage Irrigated Soil

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## ABSTRACT

**Sewage effluent is the carrier of huge amounts of N (0.09 to 0.16%), P (0.023 to 0.029 %), and K (0.11 to 0.18%) and as well as it is rich in organic carbon (3.27%). Transfer of the toxic trace metal (Pb) from the contaminated site can be seized out from the food chain through application of $FeSO_4.7H_2O$ and $CaSO_4$ in a larger area. The efficacy of the toxic metal immobilization through an application of $FeSO_4.7H_2O$ and $CaSO_4$ was studied in the laboratory and tested in the field. In batch experiments, application of $FeSO_4$ at the rate of 5% (on soil weight basis) indicated a greater decrease in soil pH (from 7.54 to 5.55) in half an hour of shaking period as a result of which water soluble and exchangeable Pb concentrations decreased by 100%. Application of $CaSO_4$ also decreases soil pH, as well as Pb concentration in soil solution. Pot culture experiments with two flower and leafy vegetable plants also show decrease in bioavailability of Pb in $FeSO_4$ treated soils.**

**Keywords:** Chemical amendments, Long term irrigation, Pb accumulations, Sewage.





## INTRODUCTION

The use of urban wastewater in agriculture is a common practice for diverse reasons, not least of which being water scarcity, fertilizers' costs, and many a times a lack of an alternative source of irrigation water (Raschid *et al*., 2006). Sewage, often untreated, used to irrigate around 10% of the world's crops, especially in urban areas, reveals the first global survey of the hidden practice of wastewater irrigation (Scott *et al.,* 2004). More than 20 million ha of land are irrigated with urban wastewater. Wastewater has an important impact on agricultural productivity and livelihoods. Strauss and Blumenthal (1990) estimated that 73,000 ha of agricultural land were irrigated with wastewater in India. A consideration of the potential availability of sewage revealed that 2,600 million $m^3$ of sewage is produced per annum in India (Arti Bhatia *et al.,* 2001). Most irrigation through wastewater in India occurs along the river banks which flow through such rapidly growing cities as Delhi, Kolkata, Coimbatore, Hyderabad, Indore, Kanpur, Patna, Vadodara, and Varanasi. Approximately 40,500 ha of land is being irrigated with urban waste water by the side of the river Musi in Andhrapradesh, India (Hoek, 2006). It is has been carried out in different districts and municipalities of Tamil Nadu for assessing the suitability of sewage water to be used in agriculture. A survey reported that urban raw sewage suffered from poor water quality

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parameters and from heavy metal contents, being above permissible levels, particularly Cd, Cr, Pb and Ni (Chandrasekaran and Rajkannan, 2003).

A city with a population of 500,000 and water consumption of 200 L $d^{-1}$ per person would produce approximately 85,000 $m^3$ $d^{-1}$ of wastewater which could carefully irrigate an area of up to 6,000 ha, the fertilizer contribution of the effluent being N - 250 kg $ha^{-1}$ $Year^{-1}$, P - 50 kg $ha^{-1}$ $Year^{-1}$, K - 150 kg $ha^{-1}$ $Year^{-1}$ (FAO,2004). Although lots of macro nutrients are added to soil, trace quantities of heavy metals also accumulate in the soil (Poornima, 2005). The more localized contamination found in urban environments is remediated through metal immobilization and mobilization that include bioremediation and chemical washing (Naidu, 2004). Removal of metals through chemical washing attracts research and commercial interest. However, very few works have been documented on heavy metal contamination of crops via sewage irrigation and none exist in relation to *Amaranthus cruentus* which is one of the most popular leafy vegetables in India. Because of the relative importance and toxicity of lead (Pb) and cadmium (Cd), even in trace concentrations, they were taken to be monitored in the present study.

Among many types of wastewater, foremost attention is being paid to sewage water due to its many attributes. Firstly, generation of sewage is inevitable in all towns and villages. Secondly, the impurity constituents of sewage are relatively less hazardous when compared with industrial effluents. Thirdly, the sewage carries considerable amounts of less complex organic matter along with essential nutrients required for plant growth. However, a prevention of bioavailability and transfer of toxic heavy metals into the food chain is the need of the hour. Therefore to address the above problems, the study was carried out in batch, pot and as well in the field.

## MATERIALS AND METHODS

Relevant materials and methods were employed to cary out batch, pot and field experiments. Field experiments were carried out on the sewage farm at Ukkadam, an intensively sewage drained area for over 65 years, located in Coimbatore peri-urban Tamil Nadu, India

### Urban Waste Water

Sewage effluent samples were collected from near the field experimental site. The samples were collected in polyethylene containers to be used in pot culture experiments at regular time intervals. The sub samples were stored following addition of toluene to arrest any microbial population and then stored at 4°C throughout the study. The samples were brought to room temperature prior to analysis. Initial physico-chemical parameters were analyzed by methods given by Standard Methods for the Examination of Water and Wastewater, (APHA 2005).

### Collection and Processing of Soil Samples

Soil samples were collected in polyethylene bags. The soil samples were shade dried and sieved through 2 mm sieves before being stored in other polyethylene bags for further analysis.

### Total Pb in Soil

The air dried and sieved soil samples were digested in aqua-regia (3:1, HCl: $HNO_3$) until white precipitate appeared in the conical flask. Following a completion of digestion, the contents were transferred to 25 mL volumetric flasks, and then the volume made up to the mark. The supernatant was later passed through Whatman No 42 filter paper stored for later on metal analyses.





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**Bio-available Fraction of Pb**

The bioavailability of metals were studied as described by Shuman (1985). For water soluble and exchangeable metals, a batch experiment was conducted using polyethylene centrifuge tubes of 40 mL capacity. Soil solution was shaken in an end to end shaker at room temperature (25°C) for 6 hours for water soluble metals. A solution ratio of 1:2.5 (10 gram of soil to 25 mL of double distilled water) was employed. Following the tubes with the contents were centrifuged at 10,000 rpm for 10 minutes and then the supernatant filtered through Whatman No 42 filter paper. Following an extraction of the soil solution, 1M $Ca(NO_3)_2$ was added to the remaining soil residue (at a ratio of 1:2.5), and kept for 4 hours in an end to end over shaker for exchangeable fraction of Pb. The rest of the extraction procedure followed was the same as that mentioned for water soluble fraction (Avudainayagam *et al*., 2003)

**Batch Experiment**

Batch experiments were conducted using centrifuge tubes of 40 mL capacity to find out the behavior of water soluble as well as exchangeable fractions of Pb in the soil. The chemical immobilizers namely $FeSO_4$ and $CaSO_4$ were added to the soil on a soil weight basis. The batch experiments were conducted in soil solutions of 1:2.5 (10 gm of soil to 25 mL of distilled water) ratios. The following chart depicts the treatments imposed for the batch experiment.

A kinetic experiment was also conducted to find out the releasing behavior of water soluble and exchangeable Pb from the sewage irrigated soil. The centrifuge tubes with their contents were shaken for various time periods of 0.5, 24, 48, and 168 hours. Following the respective shaking periods, the tubes were centrifuged with the contents processed for later analysis of water soluble and exchangeable Pb.

**Pot Culture Experiment**

As for pot culture experiment, two doses of $FeSO_4$ *viz.* 1% ($T_2$), and 2.5% ($T_3$) were taken *vs.* control. Four crops were tested in the pot culture experiment. Two crops, namely *Amaranthus dubius* ($C_1$) and *Beta vulgaris* var *bengalensis* ($C_2$) are among green leafy vegetables and two flower crops namely *Celosia argentia* ($C_3$) and *Tagetes erecta* ($C_4$). Each treatment was replicated three times. A statistical design of Factorial and Completely Randomized Design (FCRD) was employed for the study.

**Collection and Processing of Plant Samples**

Plant samples were collected from the pot culture and as well from field experiments at the end of the crop growing periods. The freshly collected crops were initially washed using tap water to remove any attaching soil particles. They were then washed, three washings with distilled water. The root, shoot and flower were separate and dried at 70°C for the coming steps. The dried plant

| Treatment | Amount (gm $kg^{-1}$ soil ) |
|---|---|
| Control ($T_1$) | Soil alone |
| $FeSO_4$ $7H_2O$* 1% ($T_2$) | 0.10 |
| $FeSO_4$ $7H_2O$* 2.5% ($T_3$) | 0.25 |
| $FeSO_4$ $7H_2O$* 5% ($T_4$) | 0.50 |
| $CaSO_4$ $2H_2O$ (Lower requirement) ($T_5$) | 0.004 |
| $CaSO_4$ $2H_2O$ (Optimum requirement) ($T_6$) | 0.008 |
| $CaSO_4$ $2H_2O$ (Higher requirement) ($T_7$) | 0.013 |

samples were ground into powder using Willey mill for further analysis. A known weight of roots, shoots and flowers of the plant samples were taken to be digested with tri-acid mixture (9: 2: 1 of $HNO_3$: $H_2SO_4$: $HClO_4$). The digested materials were filtered through Whatman No 42 filter paper and then made up to 25ml volume. The filtrates were used to measure for Pb through an Atomic Absorption Spectrometer (model Varian Spectra AA 100/200 FAAS).

### Field Experiment

Only the best performing flowering crop of *Tagetes erecta* alone was taken for study in the field conditions. In addition, $FeSO_4$ doses were further decreased to 0.5 % ($T_2$) and 1% ($T_3$) along with control treatment ($T_1$) for the field experiment. All the treatments were replicated seven times in a Randomized Block Design (RBD) of the statistical analysis.

### Statistical Analysis

The data recorded during the course of investigation was processed, tabulated and analyzed for statistical significance (Panse and Sukhatme, 1985).

## RESULTS AND DISCUSSION

Initial Characterization of Soil and Sewage

The pH around neutral 7.57, along with EC (0.57 dS $m^{-1}$) of the soil fall in the limit prescribed for irrigation for raising agricultural crops. The soil is rich in organic carbon (3.27%). In contrast, sewage contains BOD (250 to 360 mg $L^{-1)}$ and COD (490–690 mg $L^{-1}$) which are beyond the maximum level for surface irrigation (Tables 1 and 2).

### Batch Experiment

In the batch experiments, analytical grade, $FeSO_4$ and $CaSO_4$ (Merck) were used to immobilize the Pb in soil solution. Addition of $FeSO_4$ decreased the soil pH significantly and the decrease in the trend was more with increase in the dose of $FeSO_4$ (Table 3). Among the treatments, application of $FeSO_4$ 5% showed greater decrease in soil pH (from 7.54 to 5.55) within half an hour shaking period ($T_4$). The decrease in pH was gradual until 24 hours shaking period, and due to soil buffering action pH might have been stabilized at 168 hours after the shaking was stopped. Similarly, an obvious increase in soil EC was also observed in $FeSO_4$ and $CaSO_4$ treated soils (Table 4). The increase in soil EC was more pronounced in $FeSO_4$ than in $CaSO_4$ treated soil. The increase was also more with increase in the dose of treatment. Among the doses, application of $FeSO_4$ 5% showed a greater increase in EC of the

**Table 1.** Physio-chemical characteristics of sewage irrigated soil**.**

| | |
|---|---|
| Bulk density Mg $m^{-3}$ | 1.09 |
| Particle density Mg $m^{-3}$ | 2.12 |
| pH | 7.57 |
| EC dS $m^{-1}$ | 0.57 |
| Organic carbon % | 3.27 |
| Total nitrogen % | 0.12 |
| $KMnO_4$-N kg $ha^{-1}$ | 255 |
| Total phosphorus % | 0.029 |
| Olsen-P kg $ha^{-1}$ | 55 |
| Total potassium % | 0.15 |
| Available potassium kg $ha^{-1}$ | 257 |
| Total Ca % | 1.79 |
| Total Mg % | 1.01 |
| Total sodium % | 0.12 |
| Cation exchange capacity cmol ($P^+$) $kg^{-1}$ | 12.6 |

**Table 2.** Chemical characteristics of sewage effluent.

| pH | 7.59 |
|---|---|
| EC dS $m^{-1}$ | 1.21 |
| Total dissolved solids mg $L^{-1}$ | 2450 |
| Total suspended solids mg $L^{-1}$ | 2900 |
| BOD mg $L^{-1}$ | 360 |
| COD mg $L^{-1}$ | 690 |

**Table 3.** Effect of various amendments on soil pH.

| Treatment | Shaking period | | | | |
|---|---|---|---|---|---|
| | 0.5 Hrs | 24 Hrs | 48 Hrs | 168 Hrs | Mean |
| $T_1$ | 7.54 | 7.54 | 7.54 | 7.54 | 7.54 |
| $T_2$ | 6.15 | 6.01 | 6.23 | 6.21 | 6.15 |
| $T_3$ | 5.70 | 5.60 | 6.03 | 6.13 | 5.87 |
| $T_4$ | 5.55 | 5.44 | 5.70 | 6.10 | 5.70 |
| $T_5$ | 7.00 | 6.71 | 6.00 | 6.51 | 6.56 |
| $T_6$ | 7.06 | 6.63 | 6.45 | 6.57 | 6.68 |
| $T_7$ | 7.12 | 6.62 | 6.61 | 6.57 | 6.73 |
| Mean | 6.59 | 6.37 | 6.36 | 6.52 | |
| | SEd | | | CD (0.05) | |
| T | 0.05 | | | 0.09 | |
| D | 0.03 | | | 0.07 | |
| T× D | 0.09 | | | 0.18 | |

soil (from 0.77 to 3.40 dS $m^{-1}$) for a shaking period of 168 hours.

## Effect of Various Amendments on Bioavailable Pb in Batch Experiment

In order to generate quicker results, batch experiments were conducted to select the suitable amendments for immobilization of Pb in soil solution. The amendment $FeSO_4$ was found to be more effective in the immobilization of bio-available fractions of Pb in the contaminated soil as compared with $CaSO_4$ treatment. Effective immobilization of Pb was achieved when $FeSO_4$ added and mixed with the soil. Bioavailable fractions are water soluble and exchangeable ones, both of which got decreased to Below Detectable Levels (BDL) as a result of $FeSO_4$ application. This was observed for both doses of $FeSO_4$ namely 1% and 2.5% (Table 5). In $CaSO_4$ applied soil, the bio-available concentrations of Pb got below the detectable limits in the treatment of maximum $CaSO_4$ ($T_7$) applied to soil. The two remaining doses of $CaSO_4$ ($T_5$ and $T_6$) did not substantially influence the bioavailable Pb concentrations in soil.

**Table 4.** Effect of various amendments on soil EC (dS $m^{-1}$).

| Treatment | Shaking period | | | | |
|---|---|---|---|---|---|
| | 0.5 Hrs | 24 Hrs | 48 Hrs | 168 Hrs | Mean |
| $T_1$[a] | 0.67 | 0.67 | 0.77 | 0.77 | 0.72 |
| $T_2$[b] | 2.57 | 2.53 | 2.70 | 2.70 | 2.63 |
| $T_3$[c] | 2.63 | 2.70 | 2.60 | 2.50 | 2.61 |
| $T_4$[d] | 2.87 | 3.37 | 3.00 | 3.40 | 3.16 |
| $T_5$[e] | 1.43 | 1.27 | 2.80 | 2.41 | 1.98 |
| $T_6$[f] | 1.70 | 1.77 | 3.27 | 3.00 | 2.43 |
| $T_7$[g] | 2.50 | 2.67 | 2.94 | 2.45 | 2.64 |
| Mean | 2.05 | 2.14 | 2.58 | 2.46 | |
| | SEd | | | CD(0.05) | |
| T | 0.03 | | | 0.07 | |
| D | 0.02 | | | 0.05 | |
| T× D | 0.07 | | | 0.13 | |

[a] Control; [b] 1% Ferrous sulphate; [c] 2.5% Ferrous sulphate; [d] 5.0% Ferrous sulphate; [e] Lower requirement of Calcium sulphate (0.05%); [f] Normal requirement of Calcium sulphate (0.10%), [g] Higher requirement of Calcium sulphate (0.15%).

**Table 5:** Effect various amendments on bio-available Pb (mg $kg^{-1}$) in batch experiment.

| Treatment | Water soluble | Exchangeable |
|---|---|---|
| Control ($T_1$) | 0.003 | 0.003 |
| $FeSO_4$ 1% ($T_2$) | BDL | BDL |
| $FeSO_4$ 2.5% ($T_3$) | BDL | BDL |
| $FeSO_4$ 5% ($T_4$) | BDL | BDL |
| $CaSO_4$ 0.0043 g 100 $g^{-1}$ soil ($T_5$) | 0.003 | 0.003 |
| $CaSO_4$ 0.0087 g 100 $g^{-1}$ soil ($T_6$) | 0.003 | 0.003 |
| $CaSO_4$ 0.0131 g 100 $g^{-1}$ soil ($T_7$) | BDL | BDL |
| SEd [a] | 0.0001 | 0.0001 |
| CD (0.05) [b] | 0.0002 | 0.0002 |

[a] Standard error of deviation, [b] Critical difference (95%).

Addition of $FeSO_4$ might have created formation of high iron oxide precipitates (Brown colour) in the soil solution and it was observed more in $FeSO_4$ treatment of 5%. Therefore the 5% application rate of $FeSO_4$ was not included in the pot culture experiment.

## Pot Culture Experiment

The pot culture experiment was carried out to study the uptake of trace metals by green leafy vegetables and by flower crop plants and the immobilization of Pb at lower doses of $FeSO_4$ (Table 6). Both fractions of water soluble as well as exchangeable were found to be lowered to below detectable levels by an application of various doses of $FeSO_4$.

**Table 6.** Effects of $FeSO_4$ on aquaregia extratractable Pb (mg $kg^{-1}$) content in soil.

| Crop | $T_1$ | $T_2$ | $T_3$ |
|---|---|---|---|
| C1 | 55.65 | 55.27 | 55.24 |
| C2 | 55.55 | 55.36 | 55.07 |
| C3 | 55.55 | 55.37 | 55.08 |
| C4 | 55.65 | 55.43 | 55.14 |
| Mean | 55.60 | 55.36 | 55.13 |
| | | SEd | CD (0.05) |
| | C[a] | 0.053 | 0.110 |
| | T[b] | 0.046 | 0.095 |
| | C × T | 0.092 | 0.191 |

[a] Crop, [b] Treatment.

## Effect of $FeSO_4$ on Aquaregia Extractable Pb (mg $kg^{-1}$) in Post Harvested Pot Culture Soil

The aquaregia extractable Pb was slightly decreased in $FeSO_4$ applied soils in comparison with control. This decreasing trend was observed for the four crops irrespective of the crop type. The concentrations of Pb slightly decreased in $FeSO_4$ treated soil with it being higher in 2.5% amended (treated) pot (Table 7). The decrease might be due to adsorption of Pb into Fe oxides and also due to the uptake of the metal by crops in $FeSO_4$ treated soil.

Influence of $FeSO_4$ on Pb accumulation in Roots, Shoots and Flowers of Various Crop Plants (mg $kg^{-1}$) in Pot Culture Experiment

Increasing the dose of $FeSO_4$ further, decreased the translocation of Pb from soil to roots, shoots and flowers. Irrespective of type of crop plant the accumulation of Pb decreased with $FeSO_4$ application. The pot culture experiment was carried out to see the effect of $FeSO_4$ on the immobilization of bioavailable Pb and its uptake by green leafy vegetable and flowering crops (Table 8). Among the crops, Pb uptake was low in flower crops in comparison with the green leafy vegetable crops, in the face of an application of $FeSO_4$. Uptake was more in $FeSO_4$ treatment of 2.5% than in the 1%. Decrease in accumulation of Pb was observed (by order) more in roots of *T. erecta*› *A. dubius*› *B. bengalensis*› *C. argentia*

**Table 7.** Effect of $FeSO_4$ on bioavailable Pb (mg $kg^{-1}$) in pot culture experiment.

| Crops | Water soluble fraction | | | Exchangeable fraction | | |
|---|---|---|---|---|---|---|
| | $T_1$ | $T_2$ | $T_3$ | $T_1$ | $T_2$ | $T_3$ |
| $C_1$ | 0.002 | BDL | BDL | 0.003 | BDL | BDL |
| $C_2$ | 0.003 | BDL | BDL | 0.002 | BDL | BDL |
| $C_3$ | 0.003 | BDL | BDL | 0.002 | BDL | BDL |
| $C_4$ | 0.003 | BDL | BDL | 0.003 | BDL | BDL |
| | | SEd | CD (0.05) | | SEd | CD (0.05) |
| | C | 0.0001 | 0.0003 | C | 0.0004 | 0.0007 |
| | T | 0.0001 | 0.0002 | T | 0.0003 | 0.0006 |
| | C × T | 0.0002 | 0.0005 | C × T | 0.0006 | 0.0013 |

**Table 8.** Accumulation of Pb in various crops (mg $kg^{-1}$) in pot culture experiment.

| | Root | | | Shoot | | | Flower | | |
|---|---|---|---|---|---|---|---|---|---|
| Crop | $T_1$ | $T_2$ | $T_3$ | $T_1$ | $T_2$ | $T_3$ | $T_1$ | $T_2$ | $T_3$ |
| $C_1$ | 3.54 | 0.44 | 0.25 | 4.57 | 0.75 | 0.45 | - | - | - |
| $C_2$ | 3.32 | 0.52 | 0.25 | 5.24 | 0.62 | 0.42 | - | - | - |
| $C_3$ | 2.68 | 0.35 | 0.32 | 3.34 | 0.52 | 0.25 | 1.58 | 0.47 | 0.12 |
| $C_4$ | 1.68 | 0.19 | 0.09 | 1.88 | 0.25 | 0.22 | 0.36 | 0.06 | 0.04 |
| Mean | 2.80 | 0.38 | 0.29 | 3.76 | 0.53 | 0.42 | 0.97 | 0.26 | 0.08 |
| | | SEd | CD (0.05) | | SEd | CD (0.05) | | SEd | CD (0.05) |
| | C | 0.017 | 0.035 | C | 0.006 | 0.013 | C | 0.005 | 0.011 |
| | T | 0.014 | 0.030 | T | 0.005 | 0.011 | T | 0.006 | 0.013 |
| | C×T | 0.029 | 0.060 | C×T | 0.011 | 0.023 | C×T | 0.008 | 0.019 |

with the decrease being 94%, 92%, 92% and 88 % for the addition of $FeSO_4$ at 2.5 % level. The accumulation of Pb in the plants' shoots was in the order of *C. argentia*› *B. bengalensis*› *A. dubius*› *T. erecta* with the accumulation percentages being 92%, 91%, 90% and 88% respectively for the addition of $FeSO_4$ at 2.5% level. Between the two flowering crops, accumulation of Pb was more decreased in *C. argentia* than in *T. erecta* with the decrease in accumulation being 92% and 88%, respectively, as by addition of $FeSO_4$ at a 2.5% level.

## Field Experiments

The field experiments were conducted at Ukkadam sewage farm with *T. erecta* as which had performed well in the pot experiment, as the test crop. The dose of $FeSO_4$ was further decreased to 1.0 and 0.5 % for the field experiments to account for the quantity and cost effectiveness. Similar to batch and pot cultures, field experiments also showed significant decreasing trend in Pb concentration and other chemical parameters in the soil solution. The value of pH decreased from 7.55 to 6.23 in surface soil and from 7.78 to 6.47 in sub surface soil (Table 9). EC increased from 0.57 to 5.61 and from 0.59 to 5.83 dS $m^{-1}$ in surface and subsurface soils respectively for $FeSO_4$ 1%.

## Effect of $FeSO_4$ on Bioavailable Fraction of Pb in Field Experiment Soils (mg $kg^{-1}$)

Similar to batch and pot culture experiments, $FeSO_4$ application in the field experiment showed a significant decrease in bio-available fractions of Pb. Both fractions got diminished to below detectable levels in surface and subsurface





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**Table 9.** Influence of amendment addition to soil on soil pH, EC (dS $m^{-1}$) in the field experiment.

| Treatment | Surface soil (0-15 cm) | | Sub surface soil (15-30 cm) | |
|---|---|---|---|---|
| | pH | EC (dS $m^{-1}$) | pH | EC (dS $m^{-1}$) |
| $T_1$ | 7.55 | 0.57 | 7.78 | 0.59 |
| $T_2$ | 6.74 | 5.63 | 6.95 | 5.84 |
| $T_3$ | 6.23 | 5.61 | 6.47 | 5.83 |
| SEd | 0.012 | 0.017 | 0.012 | 0.016 |
| CD(0.05) | 0.026 | 0.036 | 0.026 | 0.035 |

**Table 10.** Effects of $FeSO_4$ on bioavailable Pb (mg $kg^{-1}$) in surface and sub surface soil.

| | Surface soil (0-15 cm) | | Sub surface soil (15-30 cm) | |
|---|---|---|---|---|
| Treatment | Water soluble | Exchangeable | Water soluble | Exchangeable |
| $T_1$ | 0.002 | 0.005 | 0.002 | 0.005 |
| $T_2$ | BDL | BDL | BDL | BDL |
| $T_3$ | BDL | BDL | BDL | BDL |
| SEd | 0.0002 | 0.0002 | 0.0002 | 0.0002 |
| CD(0.05) | 0.0003 | 0.0003 | 0.0003 | 0.0003 |

**Table 11.** Effects of $FeSO^4$ amendment on aquaregia extractable Pb in the field experiment soil (mg kg-$^1$).

| Treatment | Surface soil (0-15 cm) | Sub surface soil (15-30 cm) |
|---|---|---|
| $T_1$ | 110.32 | 109.44 |
| $T_2$ | 106.50 | 106.05 |
| $T_3$ | 104..30 | 103.89 |
| SEd | 0.0031 | 0.0031 |
| CD(0.05) | 0.0066 | 0.0066 |

**Table 12.** Influence of $FeSO_4$ on Pb accumulation in root, shoot and flower of T. erecta (mg $kg^{-1}$).

| Treatment | Root | Shoot | Flower |
|---|---|---|---|
| $T_1$ | 2.312 | 1.312 | 0.032 |
| $T_2$ | 0.510 | 0.315 | BDL |
| $T_3$ | 0.330 | 0.222 | BDL |
| SEd | 0.0003 | 0.000 | 0.0001 |
| CD(0.05) | 0.0006 | 0.001 | 0.0002 |

soils for both doses of $FeSO_4$ applied. (Table10)

## Effects of $FeSO_4$ on Aquaregia Extractable Pb in field Experiment Soils (mg $kg^{-1}$)

The concentrations of aquaregia extractable Pb decreased by 3, 5, 3, and 6% respectively for surface and subsurface soils for ($T_3$) treatment, this is due to addition of $FeSO_4$ and the interaction effects.

Influence of $FeSO_4$ on Pb Accumulation in Root, Shoot and Flowers of *T. erecta* (mg $kg^{-1}$)

Within the crop, Pb was more accumulated in roots than in shoots. The plant uptake rate and further translocation of Pb in *T. erecta* was decreased more as a result of $FeSO_4$ application of 1% than 0.5%. Pb was not detected in flowers of *T. erecta* for any of the doses of $FeSO_4$ applied.

## CONCLUSIONS

The results indicate that application of $FeSO_4$ greatly decreases the bioavailability and uptake of water soluble and exchangeable Pb from soil solution. The decrease in soil pH might have favoured the adsorption sites and also adsorption onto the oxides of the added $FeSO_4$ (Reddy and Patrick 1977, Ma and Uren 1997 and Hirsch and Banin 1990).

Application of $FeSO_4$ 0.5% is economically feasible and imparts more environmental benefits than the application of $FeSO_4$> 0.5%. Among the different doses of $FeSO_4$, $FeSO_4$ 0.5% decreased heavy metal bioavailability considerably, at the same time filed experiments revealed that *T. erecta* had low accumulation of Pb as compare with *C. argentia* and other green leafy vegetables. Benefit cost ratio for the treatment of $FeSO_4$ 0.5% was 1.05. The Benefit Cost ratio can be very much improved if includes the value of the environmental benefits. The chemical immobilization of trace metals in sewage contaminated sites will prevent the transfer of metals to the food chain and also stop the downward movement of the heavy metals into subsurface soil, which otherwise could cause the eventual contamination of ground water.

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# تثبیت شیمیایی سرب (Pb) در خاک آبیاری شده با فاضلاب به مدت طولانی

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## چکیده

پساب فاضلاب حاوی مقادیر قابل توجهی نیتروژن (۰/۰۹ تا ۰/۱۶ ٪)، فسفر(۰/۰۲۳ تا ۰/۰۲۹ ٪) و پتاسیم (۰/۱۱ تا ۰/۱۸ ٪) بوده و همچنین غنی از کربن آلی (۳/۲۷٪) می‌باشد. در هنگام آبیاری با این آب، فلزات سمی نیز در منطقه انباشته می‌شوند. برای جلوگیری سریع از انتقال فلز کمیاب سمی سرب از خاک آلوده به محلول خاک و ورود آن به چرخه غذا می‌توان از $FeSO_4.7H_2O$ و $CaSO_4$استفاده نمود. در این مطالعه، کارایی تثبیت $FeSO_4.7H_2O$ و $CaSO_4$در آزمایشگاه و مزرعه مورد بررسی قرار گرفت. در آزمایش ناپیوسته، استفاده از $FeSO_4$ به میزان ۵٪ بر مبنای وزن خاک باعث کاهش شدید pH خاک از ۷/۵۴ به ۵/۵۵ در مدت نیم ساعت تکان دادن و در نتیجه کاهش صددرصدی در غلظت سرب قابل تبادل و محلول در آب گردید. استفاده از $CaSO_4$ نیز موجب کاهش pH و همچنین غلظت سرب در محلول خاک گردید. آزمایش های کشت گلدانی با استفاده از دو نوع گیاه (گلدار و برگی) نیز کاهش دسترسی زیستی سرب را در خاک های تیمار شده با $FeSO_4$ نشان داد.





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