Phytoremediation of Heavy Metal Contaminated Soil by *Psoralea Pinnata*

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***Abstract*—Soil contaminated with iron and chromium was planted with *Psoralea pinnata* under greenhouse condition. The growth of the plants and phytoextraction of the metal contaminants from the soil were studied for a period of three months. The results showed that *Psoralea pinnata* was able remove both chromium and iron from the contaminated soil during the period of experimentation. The percentage reduction in chromium and iron concentrations in the experimental soil varied greatly at different concentration of both contaminants in the two soils used. It was observed however that at some points in the experiment involving mixed concentration of iron and chromium, there were preferences on accumulation of metals by *Psoralea pinnata.* Results show that chromium was initially most accumulated by *Psoralea pinnata* (up to 68%). As the concentration of contaminants increased, at high concentrations, iron was recorded to have been accumulated more in *Psoralea pinnata* (up to 55%).**

***Index Terms*—Chromium, iron, phytoextraction, *Psoralea pinnata*.**

I. Introduction

Soils contamination by heavy metals and metalloids has become a serious environmental issue today. A number of metals including chromium, iron, arsenic, zinc, cadmium, mercury and copper are known to significantly compromise the quality of soil and cause adverse effects to human and health and the well being of other organisms that comes in contact with such soil. Heavy metals are extremely persistent in the environment because they are not biodegradable and may not be broken down by chemical oxidation [1] or through thermal processes, as a result their accumulation readily reaches to toxic levels [2]. Some metals are essential for plant growth however, very high or low concentrations of some these heavy metals may be inhibitory to plant growth. Human activities such as metal smelting, electroplating and mining are sources through which heavy metals enter the environment. According to Kuhndt [3], about 100-350 tons of residues are generated during the extraction processes for every ton of copper produced. South Africa has about 70% of the world's chrome reserve and is the world's largest producer of ferrochrome (75%). South Africa has about 6000 abandoned mines most of which have potential to contaminate the environment [4]. The contamination of soil with heavy metals in each of the sites is dependent on length of operation of mines. Rain and runoff waters help to increase the chance of extending metal contamination beyond the primary contaminated sites. Metals have the potential to accumulate in human body when contaminated plants are ingested and may produce unwanted side effects [5]-[7]. Methods used for remediation of heavy metal contaminated soil include soil flushing, solidification/stabilization, vitrification, thermal desorption and encapsulation [8]. Other methods include burying of the contaminated soil or dilution of the contaminated soil with clean soil. These methods contribute to long-term risks such as leaching into groundwater and surrounding soil [1].

Due to the expensive nature of the conventional remediation methods for heavy metal contamination [9], phytoremediation technologies are continuously being researched for possible solutions. The level of heavy and toxic metals (Pb, Cr, Hg, etc.) in the environment can be reduced from contaminated sites or media using a number of aquatic and terrestrial plants. Metals are taken up in solution by the root system of plants and transported to the stems and leaves without showing toxicity syndromes and this have been supported by many studies [10], [11]. As a developing technology [12], phytoremedaition, particularly phytoextraction have been applied to metals contaminations containing (e.g. Ag, Cr, Fe, Cu, Hg, Mn, Mo Ni, Pb, Zn), metalloids (e.g. As, Se), radionuclides (e.g. 90Sr, 137Cs, 234U, 238U) and non-metals [13], [14]. Phytoextraction employs plants to transport and accumulate high quantities of metals from soil into the harvestable parts of roots and above ground shoots [15], [16], and has emerged as a cost effective, environmentally friendly clean up alternative [17]. The phytoextraction or hyperaccumulation of metals in various plant species have been extensively investigated and substantial progress has been made. The potential of *duck* weed was investigated by Zayed *et al*. [18] for the removal of Cd, Cr, and Cu from nutrient-added solution and the results indicated that *duck* weed is a good accumulator for Cd and Cu, but his result was unable to establish potential plant for abstracting Cr from the soil. Brooks, [19] investigated the uptake of Cr from soil by the use of some plants including Indian mustard (*Brassica juncea*). He indicated that there is no evidence of Cr hyperaccumulation by any vascular plants. Robinson *et al.* [20] investigated the potential of *Berkheya Coddii* to phytoextract Co from artificial metalliferous media. Although, Co was readily taken up by the plant, cobalt was toxic to the plant above a certain limit. Although, majority of phytoextraction investigations have focused on Cd, Pb and Zn [21], Fe contamination is a more prominent problem in many soils particularly where iron extraction is common and

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where conversion of iron into various kinds of steel carried out.

The hyperaccumulators that have been extensively studied includes *Thlaspi spp.*, *Arabidopsis spp.*, *sedum alfredii spp.*, belonging to the families *Brassicaceae* and *Alyssum* [22]. *Psoralea pinnata* belongs to the family *Fabaceae* thriving well in both wetland and upland habitats. The use of *Psoralea pinnata* in phytoextraction has not been investigated. The aim of this study is to investigate the use of *Psoralea pinnata* in phytoextracting Fe and Cr from contaminated soil under green house conditions.

II. Materials and Methods

A. Plant

Psoralea pinnata, seeds were collected from Silver Hills Seeds and Brook, Cape Town. The seeds were planted and watered in a green house for four weeks. Healthy plants with a height of about 11.50cm were selected for the phytoextraction experiments.

B. Treatments

TABLE I: Characteristics of the Soil Used in the Experiments

	Garden soil	Commercial Potting Soil
pH-H_2O	7.41±0.25	6.43±0.49
CEC (meq/100g soil)	11.2	21.8
Organic carbon ((% wt))	12.12	0.87
N_{tot} (% wt)	0.02	0.05
P_{tot} (% wt)	4.4	9.1
K (ppm)	3.2±0.29	14.8±0.52
Sand (%)	63.9	8.9
Silt (% wt)	15.3	18.0
Gravel (% wt)	≤ 5	N/A
Clay (% wt)	19.0	69.8
Ca (ppm)	61.5±0.39	82.8±0.53
Mg_{tot} (ppm)	1.5±0.79	8.5±0.82
Mn (ppm)	9.7±0.89	75.6±0.64
Na(ppm)	147±0.03	44.0±0.61
Fe_{tot}(ppm)	57.2±0.61	4.6±0.45
Cr_{tot} (ppm)	78.0±0.27	10.2±0.31

The two soils types were separately mixed with compost in a ratio of 5:1 (w/w) (soil: compost) (see Table I). Eight experiments were set up in triplicates in PVC pots (550 × 413mm) by contaminating each soil with a 1.5:1 ratio (v/v) of Cr ($KCrO_4$) and Fe ($Fe(NO_3)_3.9H_2O$) to mimic the composition of both metals in a typical ferrochrome. The combined total concentration of both metals in the treatments ranged from 40 to 320 mg kg^{-1}. The treatments for both soil types contained Cr and Fe in mg kg^{-1} as follows:

T_{40} = 24 Cr + 16 Fe, T_{80} = 48 Cr + 32 Fe, T_{120} = 72 Cr + 48 Fe, T_{160} = 96 Cr + 64 Fe, T_{200} = 120 Cr + 80 Fe, T_{240} = 144 Cr + 96 Fe, T_{280} = 168 Cr + 112 Fe, T_{320} = 192 Cr + 128 Fe

Two sets of control experiments were separately set up using the garden soil and commercial potting soil without metals. Four week old Psorelea pinnata plants from the nursery were transplanted into the contaminated soils and the controls and allowed to grow for 3 months in the green house. Moisture was kept at 60-70% field capacity. Leaching was avoided by adding only a little amount of the water at a time.

Plants were harvested after 3 months growth, washed, dried and homogenised before digesting 15g in a mixture of HNO_3 : HCl (1:3) and analyzing in Atomic Absorption Spectrophotometer (AAS)

Ten grams of soil samples were digested in an acid mixture of HNO_3 : HCl (1:3). The chromium and iron content of the samples were analyzed using Atomic Absorption Spectrophotometer (AAS).

III. Results and Discussion

The result of the analysis of the two soils are shown in Table 1. Most measured parameters including organic carbon varied considerably in both soils. The results of analysis for Cr and Fe in plant tissues from the experimental plants shows that the plant tissues accumulated between 12 and 27% Cr and 18 and 22% Fe of the amount of Cr and Fe present in the garden soil. The largest amounts (%) accumulated were in T_{40} (27), T_{80} (20) and T_{120} (20.5) for Cr (see Fig. 1) and T_{40} (20.5), T_{160} (21) and T_{200} (22) for Fe (see Fig. 2).

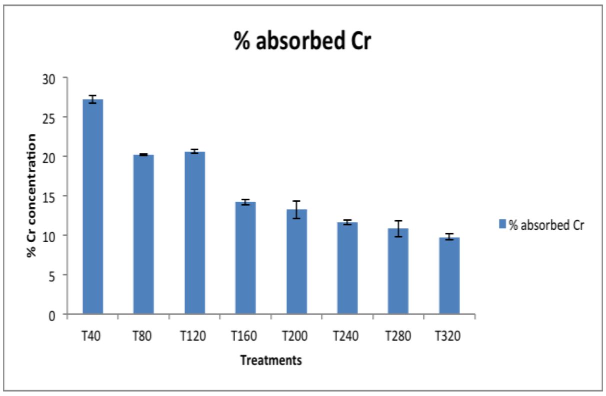

Fig. 1. Amount of Cr accumulated in plant tissues (% of soil concentration) in garden soil. Values are means of 3 +/- SE.

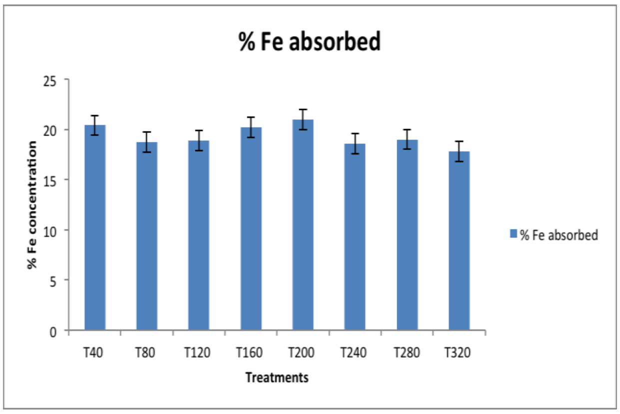

Fig. 2. Amount of Fe accumulated in plant tissues (% of soil concentration) in garden soil. Values are means of 3 +/- SE.

Both metals were taken up well by the experimental plants. The difference in the concentration of Fe between T_{40} and T_{320} in the mixed contamination in the garden soil did not significantly affect the rate of accumulation of Fe in the plant tissues. However, the rates of accumulation of Cr was significantly affected by the increases in concentrat. Although all plants grew well in the soil, leaf yellowing was observed in some of the plants in $T_{240}-T_{320}$.

Generally, there tended to be a decrease in the amount of both metals accumulated as concentration of metals increased. This is an indication of toxicicty at elevated concentrations, however, it could not determined which of the metals was responsible for the toxic effect or whether the effect was due to both metals.

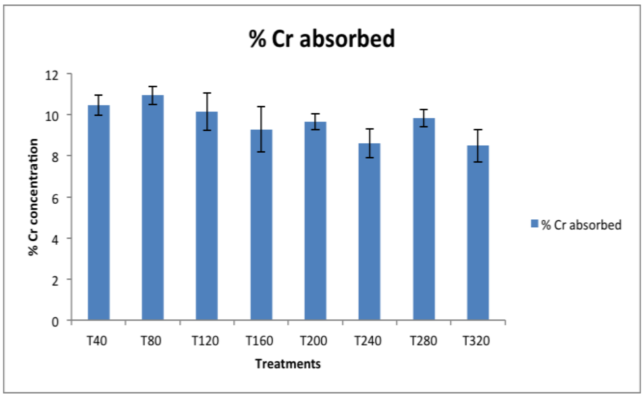

Fig. 3. Amount of Cr accumulated in plant tissues (% of soil concentration) in commercial potting soil. Values are means of 3 +/- SE.

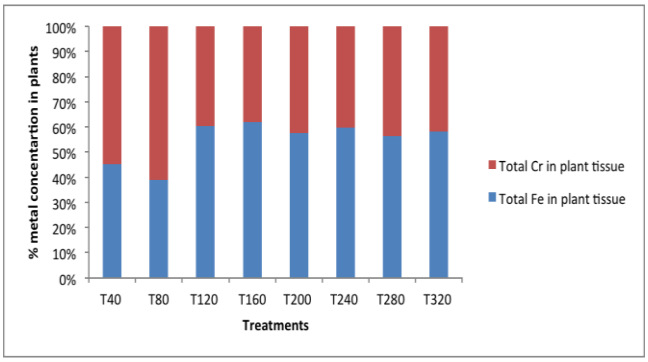

Fig. 4. A comparison of the amounts of Cr and Fe accumulated in plant tissues in garden soil. Values are means of 3 +/- SE.

Changes in metal concentration did not significantly affect the rate of accumulation of Cr in the commercial potting soil (see Fig. 3). The difference in the responses to concentration of the metals could not be readilly explained. However, there were a number of differences in both chemical and physical parameters of the two soils. The cation exchange capacity and (CEC) and the organic carborn are to parameters that could be responsible for the difference. From Treatments T40 to T160, Cr was the dominant metals accumulated by *Psoralea pinnata* in preference to Fe. In the Treatment T200, there was no significant difference between the accumulation of Cr and Fe although the accumulation of Fe was slightly higher (see Fig. 4). The treatment with the most iron absorption in relation to chromium absorption is T320. It was observed that with rising concentration of metals in the soil, *Psoralea pinnata* absorbed more of Fe than of Cr.

The results show that plants in the control experiments with garden soil and commercial potting soil showed a very low amounts of both metals. The total amounts of Fe accumulated in the garden soil 6.34% and 1.38% in the commercial potting soil. The total amounts of Cr accumulated in the garden soil was 3.48% and 3.11% in the commercial potting soil. These results are not unexpected, as the control experiments were not spiked with Fe and Cr and the concentrations of both metals in the soil were very low (see Table I).

These results support those of previous studies where it was observed that there was competition between Cr and other metals for binding sites. Sharma and Pant, [23], showed that in maize plants, the effects of Cr on Fe concentration varied with plant organs and also with Cr levels. They observed that Mn, Fe and Cu concentrations generally decreased with increase in Cr levels. In a study on Cr (III)–Fe interaction, Bonet *et al.* [24] reported that Cr enhanced growth of both Fe-controled and Fe-deficient plants. However, Cr concentrations correlated neither with changes of Mn, P nor Fe tissue concentrations or Cr-induced alterations of the Fe/Mn and P/Fe ratios. The reduction in the uptake of Fe could be mainly due to the chemical similarity of Fe and Cr ions in solution. Hence, the competitive binding to common carriers by Cr (VI) could have reduced the uptake of many nutrients [25].

IV. Conclusion

From the results obtained in this study, Psorelea piñata has demonstrated that it can accumulate Fe and Cr in contaminated soils under green house conditions. It has also shown that it can tolerate high levels of metal contamination with minimal inhibition in growth processes. It would therefore be a useful plant to test further for hyperaccumulation of toxic heavy metals.

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