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Research Article

Biochar and Manure Based Phytoremediation Study for Hyperaccumulation of Chromium Using *Cymbopogon flexuosus (Nees ex Steud.)* Will.Watson and *Crysopogon zizanioides (L.)* Robertys

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Abstract

Chromium (Cr) contamination in soil is a growing concern for sustainable agricultural production, food safety and to minimize the adverse environmental impacts. Pot experiments were conducted for 90 days in Bioremediation lab to investigate the phytoremediation potential of Lemongrass *(Cymbopogon flexuosus*) and Vetiver (*Crysopogon zizanioides)* grown in different composition of chromium (Cr) rich overburden soil (OBS) of Sukinda Chromite Mine. To assess the phytoaccumulation ability of *Cymbopogon flexuosus* and *Crysopogon zizanioides*, the bio-accumulation factor (BAF) and total accumulation rate (TAR) were measured. The final results showed that the highest accumulation of Cr was observed in T9 of Vetiver i.e. 688.08 mg/Kg and T6 of Lemongrass i.e. 570 mg/Kg. Similarly the highest BAF and TAR of Cr was observed in T9 of Vetiver i.e. 0.408, T6 of Lemongrass i.e. 0.338 and T9 of Vetiver i.e. 7.64, T6 of Lemongrass i.e. 6.33 respectively. The outcome indicated that these two grass species Cymbopogon flexuosus and Crysopogon zizanioides is a potential phytoremediator of Cr from contaminated sites due to its high bioaccumulation activity with high tolerance. Hence we suggest these two species can be recommended for phytostabilization and phytoextraction of toxic Cr from the low grade chromite.

Keywords: *Chromium, Lemongrass, Vetiver, Phytoaccumulation, Bio-accumulation factor , Total accumulation rate, Phytostabilization.*

Introduction

Chromium (Cr) is the seventh most abundant metal in the earth's crust [Katz and Salem, 1994] and an important environmental contaminant released into the environment due to its huge industrial use [Nriagu and Nieboer, 1988]. In nature, Cr exists in two different stable oxidation states i.e., trivalent (Cr^{+3}) and hexavalent (Cr^{+6}) forms. Cr^{+3} and Cr^{+6} differ in terms of mobility, bioavailability and toxicity. Cr^{+6} have been found to be more toxic than Cr^{+3} [WHO, 1988; Panda and Patra, 1997; Panda, *et al*., 2003, Mohanty, M and Patra, HK. 2011; Das, *et al*., 2014]. Cr is a broad line heavy metal and is phytotoxic in some cases above certain threshold levels [Nieboer and Richardson, 1980, Mohanty, M. *et al*., 2015]. Cr Phytotoxicity can result in inhibition of seed germination, degrade pigment status, alter nutrient balance, and increase the activity of antioxidant enzymes and induction of oxidative stress in plants [Barceló and Poschenrieder, 1997; Panda, *et al*., 2003]. Cr also retards growth, reduces the number of the palisade and spongy parenchyma cells in leaves [Han, *et al*., 2004]. A consequence of a wide range of biotic stress including heavy metals, toxic reactive oxygen species (ROS) like H_2O_2, O_2^- , OH^- etc. are produced.

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Production of H_2O_2 , O_2^-, OH^- under Cr stress have been demonstrated in many plants, generating oxidative stress leading to damage of DNA, proteins and pigments as well as initiating lipid peroxidation [Panda and Patra, 2000; Panda, *et al*., 2003].

Pollution in soil and water caused by heavy metal like chromium (Cr) vary from air pollution, because chromium exist in soil and water for long time than other medium of the biosphere [Ahmad A and Alam M. 2002, 2003]. Chromium is one of the modern industry's essential elements whose strategic importance is attributed to critical application in defense, aerospace, aviation, paints, dyes, chrome plating industries, and so on. Extensive open-caste mining and industrial activities release a considerable quantity of mine wastewater and effluents containing toxic levels of hexavalent chromium (Cr^{+6}) at the operational sites causing environmental contamination and hazards. The storage of overburden soil (OBS) during post mining operations is commonly identified as one of the most important crisis in respect of mining pollution. The fact that the volume of OBS requiring storage can often exceed the in situ total volume of the soil mined and processed. India being the world's sixth largest iron and chromite ore producer generates about 18 million tons of waste tailings annually. The vast quantity of generated mine waste is one of the biggest challenges in mining industry for its sustainable management.

Currently $6–8 billion a year is spent on environmental clean-up in the United States, and $25–50 billion per year worldwide [Glass DJ., 1999, Tsao DT.,2003]. India has fairly large resources of chromium mostly concentrated in the state of Odisha (India). Odisha is endowed with vast mineral deposit of chrome ore and hosts the largest chromite reserve of the country. Odisha accounts for 98%of the total chromium deposits of India. It noted that higher concentration of chromium in mine adjoining areas poses threat to biotic communities due to the fact that the metal is toxic to biological system [Katz. SA and Salem, H. 1994., Patra, D. et. al, 2019]. Metabolic alterations by chromium exposure have also been described in plants either by a direct effect on enzyme or other physiological changes or by alterations in biochemical parameters [Patra, D. et. al, 2018].

Under chromium stress, total chlorophyll and protein contents were reduced in sesban and para grass plants as Cr causes iron insufficiency in stressed plants as a result reduction in chlorophyll biosynthesis and denaturation of protein [Patra, D. et. al, 2020, Verbroggen, N. and Hermanas, C., 2008]. Chromium stress significantly increased the concentration of proline and the activities of antioxidant enzymes in plants, which might be a strategy adopted by the plants to cope up with the Cr toxicity.[Patra, D. et. al, 2018, Verbroggen, N. and Hermanas, C., 2008, Patra, D. et. al, 2018] With a view to tackle the severe problem of contamination of toxic Cr^{+6}, attempts have been taken for attenuation of Cr^{+6} through the use of phytoremediation technology [Patra, D. et. al, 2019, Patra, D. et. al, 2018].

Phytoremediation is a green emerging technology which involves the use of metal accumulating plants (or) metal-tolerant plant;s for remediating metal contaminated soils. The success of phytoremediation depends on the choice of plant species. Cymbopogon flexuous (Nees ex Steud.) W.Watson is a genus of Asian, African, Australian and Tropical regions and popularly known as Lemongrass. Within the grass family, Lemongrass is widely used as a medicinal herb. It is with subtle citrus flavor and can be used as dried and powdered or fresh. Lemongrass oil can be used as a pesticide and preservative. However, the species has not yet been tested for its phytoremediation ability and stabilization potential in chromium contaminated soil. In this technology plants are used to alleviate the toxic metals from polluted sites through their accumulation in harvestable aerial portions (i.e., phytoextraction) or phytostabilization of toxic metals in soil in contaminated sites. The studies confirmed that the plants have unique ability to reduce contamination of Cr^{+6} by different method of phytoremediation [Patra, D. et. al, 2018]. So far, no effort has been undertaken for attenuation of chromium from OBS of Sukinda Chromite Mine, Odisha with chromium as contaminant by using Lemongrass *(Cymbopogon flexuosus)* and Vetiver *(Crysopogon zizanioides)* plant. The chromium phytostabilizaion program using OBS at mining site is a problem for the state of Odisha in respect of mining pollution. Therefore, the objective of the experiments were to study (a) elucidation of phytotoxic impacts of chromium-contaminated OBS on growth of Lemongrass *(Cymbopogon flexuosus)* and Vetiver *(Crysopogon zizanioides)* plants (b) Cr bioaccumulation in different plant under varied levels of Cr toxicity stress (c) Assessment of hyperaccumulation ability for Cr, its uptake by evaluating bio-accumulation factor (BAF) and Total accumulation rate (TAR) (d) Suggestive measures for lab scale to field-scale approach for heavy metal remediation and field application in contaminated soil.

Materials and Methods

Experimental Setup and Treatment Application

A pot culture study was laid out on IMMT Garden site to assess the phytoremediation, growth and physiological response of two hyper accumulator grass species *C. flexuosus* and *C. zizanioides*. The grass slips were brought from the IMMT Garden, for Vetiver the root and shoot lengths were 27 cm and 3 cm and for Cymbopogon the root and shoot lengths were 22 cm and 8 cm respectively. Several pot experiments were done in the past by researchers to analyse the effect of phytoremediation and uptake mechanism by different plants, so here we have tried with some different composition mixtures to observe the phytoremediation ability of these two grass species. Plastic Pots were used and filled with 1 kg of soil mixture where Bio-char concentration is 10g/1 kg, DAP (Di-ammonium Phosphate) concentration is 1 L/ 20 L and Cow dung concentration is 50g/ 1 kg, we are also using Sukinda's Chromium over burden soil (OBS) in this experimental soil mixture for the assessment of the phytoremediation. Each experimental pot contains 2-3 Vertiver & Lemon Grass slip. The total length of experiment was set to be of 3 months, where the grass slip samples are collected from the pots within the interval of 15 days, 1 month, 2 month and 3 month respectively. Also soil without any dose of Cr (IMMT Garden Soil) was used as control. The Experimental field setup was as follows-

Table 1: Treatments of soil with different composition of CW, BC and DAP

Treatment	Composition		
T1 (Control)	Control (IMMT GS)	Control	Control
T2 (Control)	GS + CW	GS+ CW	GS + CW
T3	OBS	OBS	OBS
T4	OBS+ CW	OBS+ CW	OBS+ CW
T5	OBS + CW+ DAP.	OBS + CW + DAP.	OBS + CW + DAP.
T6	OBS + DAP.	OBS + DAP.	OBS + DAP.
T7	OBS + BC	OBS + BC	OBS + BC
T8	OBS+ BC + CW	OBS + BC + CW	OBS + BC + CW
T9	OBS + DAP + CW + BC	OBS + DAP + CW + BC	OBS + DAP + CW+ BC

OBS- Overburden soil, BC- Biochar, DAP- Di ammonium phosphate, CW- Cow dung, GS- Garden soil

Physico- Chemical Analysis of Soil

Agricultural sandy loam soil was obtained from CSIR- IMMT and analysed for physicochemical variables (Table-2).Using (Systronics Multi-parameter 371) pH and EC of the Soil is determined. C, N, S is determined by CHNS analyser. Total Na, K, Ca was determined using flame photometer. The heavy metals are analysed by AAS (Atomic Absorption Spectroscopy) and ICP-

OES (Inductively Coupled Plasmon Atomic Emission Spectroscopy).

Fig 1: Preparation of soil mixtures for Experiment

Fig 2: Sowing of Lemon & Vetiver Grass Slips in the Pots

Fig-3: Experimental Setup

Statistical Analysis

Soil and plants materials were collected and statistically analyzed. The treatments were carried out in triplicate and the data furnished in figures and tables are mean ±SEM (standard error of the mean of three replicates). The data were subjected to two-way analysis of variance (ANOVA) for inter comparison of various treatments where Fischer's (F) values were calculated at 5% level of significance following the standard method.

Growth Parameters

The growth parameters, viz root length, shoot length, fresh weight and dry weight of 90 days Lemongrass plants were taken up for the study. 90 days plant were harvested for measurement of root and shoot length. Fresh and dry matter content of treated samples was also measured.

Total Chromium Content and its Bioavailability

The soils samples were air-dried and ground using a mortar and pestle. The samples were kept for few days in an oven and dried at 60^0 C to constant weight, subsequently digested in aquaregia using HNO_3: HCl (1:3) [Patra, D. et. al, 2019, Verbroggen, N. and Hermanas, C., 2008, Patra, D. et. al, 2018]. The harvested plant samples were analyzed for total Cr content in plants. Before analysis of total Cr content, the roots were rinsed with 0.01 N HCl followed by washing with distilled water to remove mixed Fe and Cr hydroxides, which may have precipitated on the root surfaces. Roots and leaves of 90 days old Lemongrass and Vetiver plants from different treatment pots were ovens dried and ground separately to fine powders. HNO_3: HCl in the ratio of 1:3 was added to the weighed and ground plant powder samples (roots and leaves) separately and kept for 24 hours [Arnon, DI. 1949, Porra, RJ. 2002, Patra, D. et. al, 2018]. Then the acid mixed plant samples were digested and extracted for metal content using (Fumehood Digestion Unit) (FM-250; Bio Lab Ltd., Kolkata, India). The acid digested solutions were filtered through Whatman No.1 filter paper and the final volume was made up to 100 ml with deionised water. Total Cr bioaccumulation in different parts of plants was estimated by analysing those extracted liquid samples in an atomic Absorption Spectrophotometer. (Analyst 200; Perkin Elmer, USA).

Chromium Tolerances Indices

Metal accumulation in plants was analyzed for calculation of Bio-concentration Factor (BCF) and Total Accumulation Rate (TAR) as per formulae adopted previously [Ahmad, A. et. al., 2011, Zurayk, R. et. al., 2002, Ghosh, M. and Singh, SP. 2005].

BCF= Average chromium concentration in the plant tissue (mg kg-1) / Chromium added in soil (mg kg-1)

Results

Table 2: Analysis of Soil samples from pot culture study

Soil analysis Parameters	Sample from pot IMMT Garden soil (GS)	Sample from pot Overburden soil (OBS)
pH	5.62± 0.3	6.93± 0.3
EC (µS/m)	228	10.4
Soil Organic carbon (%)	0.63	0.317
Water Holding Capacity (%)	34.42	46.62
Total nitrogen (%)	0.97	0.001
Total calcium (ppm)	12.23	50.76
Total Sodium (ppm)	0.6	3.8
Total potassium (ppm)	7.18	6.32
Fe (ppm)	1.488	11698
Cr (ppm)	**1.829**	**1683**
Cr^{6+} (ppm)	**1.12-1.24**	**1178.1**
Mg (ppm)	0.76	319
Ni (ppm)	0.009	86.6
Pb (ppm)	0.066	1.25
Zn (ppm)	1.239	16.57
Mn (ppm)	10.86	131.23

Analysis of Soil Samples used in this Pot Culture Study

The above table showing the result of different physic-chemical parameters of the soil sample collected from IMMT garden and Sukinda Chromite overburden soil. The pH of the GS and OBS are 5.62± 0.3 and 6.93± 0.3 respectively. The EC of GS and OBS are 228 µS/m and 10.4 µS/m. The Soil Organic carbon percentage of GS and OBS are 0.63% and 0.317% respectively.

Water Holding Capacity percentage of GS and OBS are 34.42% and 46.62%. Total nitrogen percentage of GS and OBS are 0.97% and 0.001% respectively. Total calcium content in GS and OBS are 12.23 ppm and 50.76 ppm. Total Sodium content in GS and OBS are 0.6 ppm and 3.8 ppm respectively.Total potassium content in GS and OBS are 7.18 ppm and 6.32 ppm respectively. The above work is based on chromium, so the Chromium (Cr) content in GS and OBS soil are 1.829 and 1683 ppm respectively. Hexa-valent (Cr^{6+}) content in GS and OBS soil are 1.12-1.24 ppm and 1178.1 ppm respectively. Apart from Chromium the other elements like Iron (Fe), Magnesium (Mg), Nickel (Ni), Lead (Pb), Zinc (Zn) and Manganese (Mn) were also analyzed for their presence in the soil.

Fig 4: Digestion of soil and Plant samples

Fig 5: Analysis of soil and plant samples through Atomic Absorption Spectrophotometer

Bio-Availability of chromium in Lemongrass and Vetiver plants

The concentration of chromium at the matured stage in plants ranged from **2.7 to 16.2 mg/kg** with a fourfold difference from uppermost to lowermost concentration. The bioaccumulation of Cr in roots and shoots of weeds grown in South Kaliapani area of Sukinda showed that roots have accumulated more Cr than shoots.[41] The accumulation of chromium gradually upsurges in roots and shoots of the plants with increase in the concentration of chromium. At maturity stage, in all treatments the BAF showed significant difference between highest and lowest values. The quotient of Cr content in plants was measured to assess the translocation of Cr from rhizospheric to aerial part of the these plants. The variances in TAR value might be affected by physico-chemical properties of soil and genotype of the plant.

Table 3: A comparison of chromium concentration in soil and Lemongrass plants after 15, 30, 60 and 90 days of plantation

Treatment	Amount of Cr in soil (mg/kg)	Amount of Cr in plant (mg/kg) 15days	Amount of Cr in plant (mg/kg) 30days	Amount of Cr in plant (mg/kg) 60days	Amount of Cr in plant (mg/kg) 90days
T3	1683	54.75	66.6	349.08	262.2
T4	1683	30.25	137.3	312.6	86.64
T5	1683	17.1	43.5	283.32	530.16
T6	1683	15.8	24.4	479.52	570
T7	1683	16.55	134.6	213.72	501
T8	1683	22.15	152.8	203.28	51.48
T9	1683	18.4	41.1	321.24	103.2

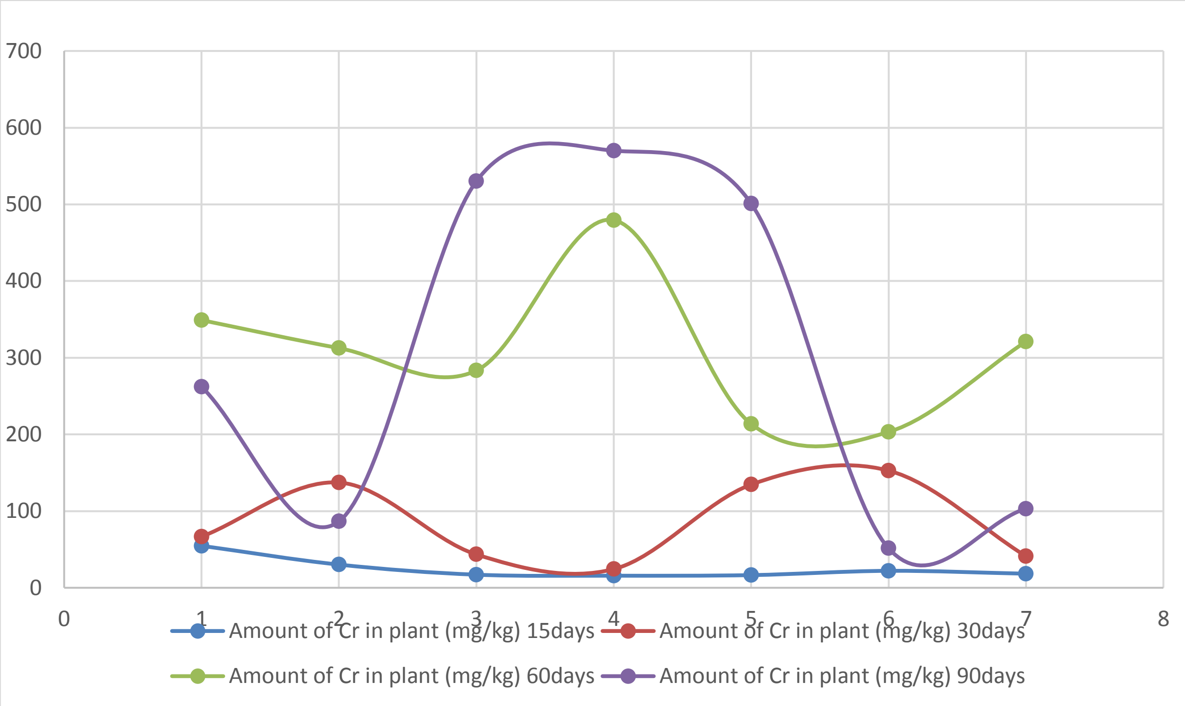
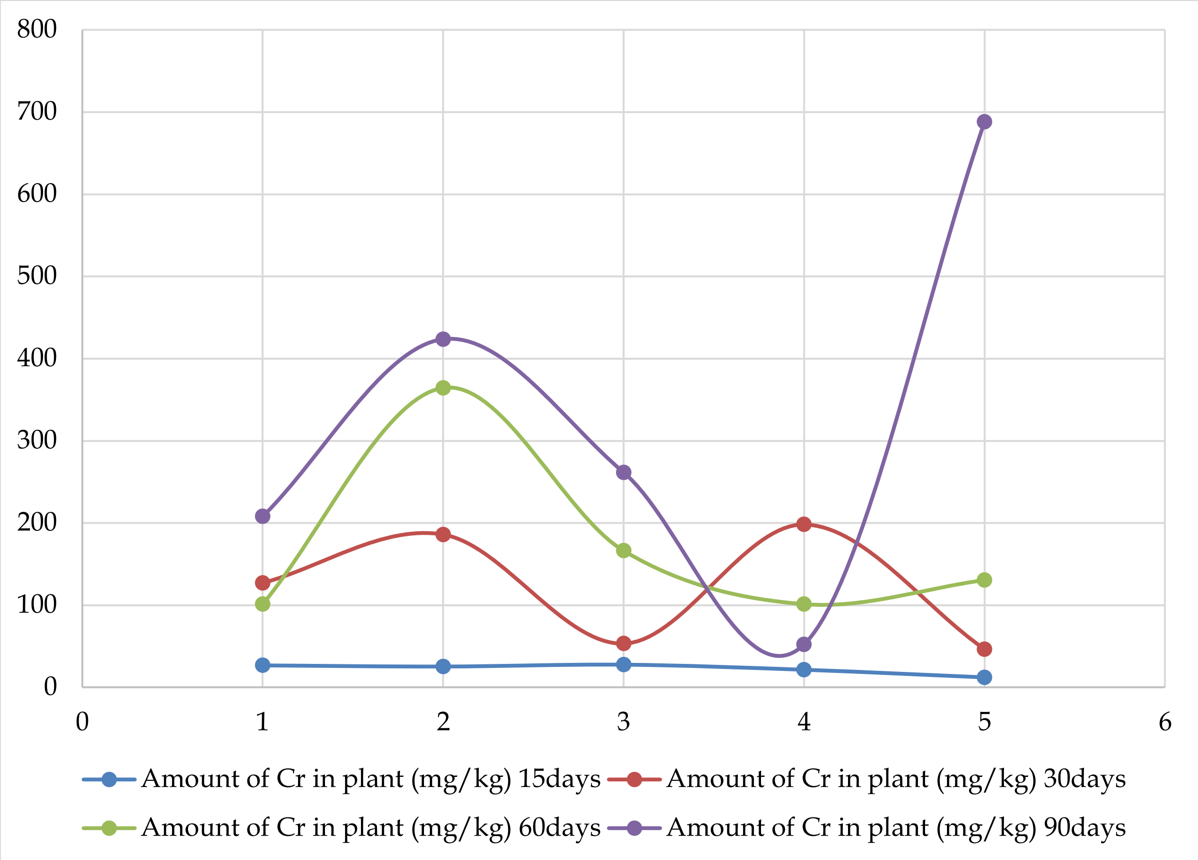


Table 4: A comparison of chromium concentration in soil and Vetiver plants after 15, 30, 60 and 90 days of plantation

Treatment	Amount of Cr in soil (mg/kg)	Amount of Cr in plant (mg/kg) 15days	Amount of Cr in plant (mg/kg) 30days	Amount of Cr in plant (mg/kg) 60days	Amount of Cr in plant (mg/kg) 90days
T3	1683	73.35	47.95	205.56	78.84
T4	1683	69.4	94.8	78.24	173.32
T5	1683	26.75	127.0	101.28	207.96
T6	1683	25.4	186	364.44	423.72
T7	1683	27.65	53.3	166.32	261.6
T8	1683	21.45	198.2	101.28	52.32
T9	1683	12.2	46.5	130.56	688.08



The Bioaccumulation factor is the accumulation of metals from the soil to the plant tissue.

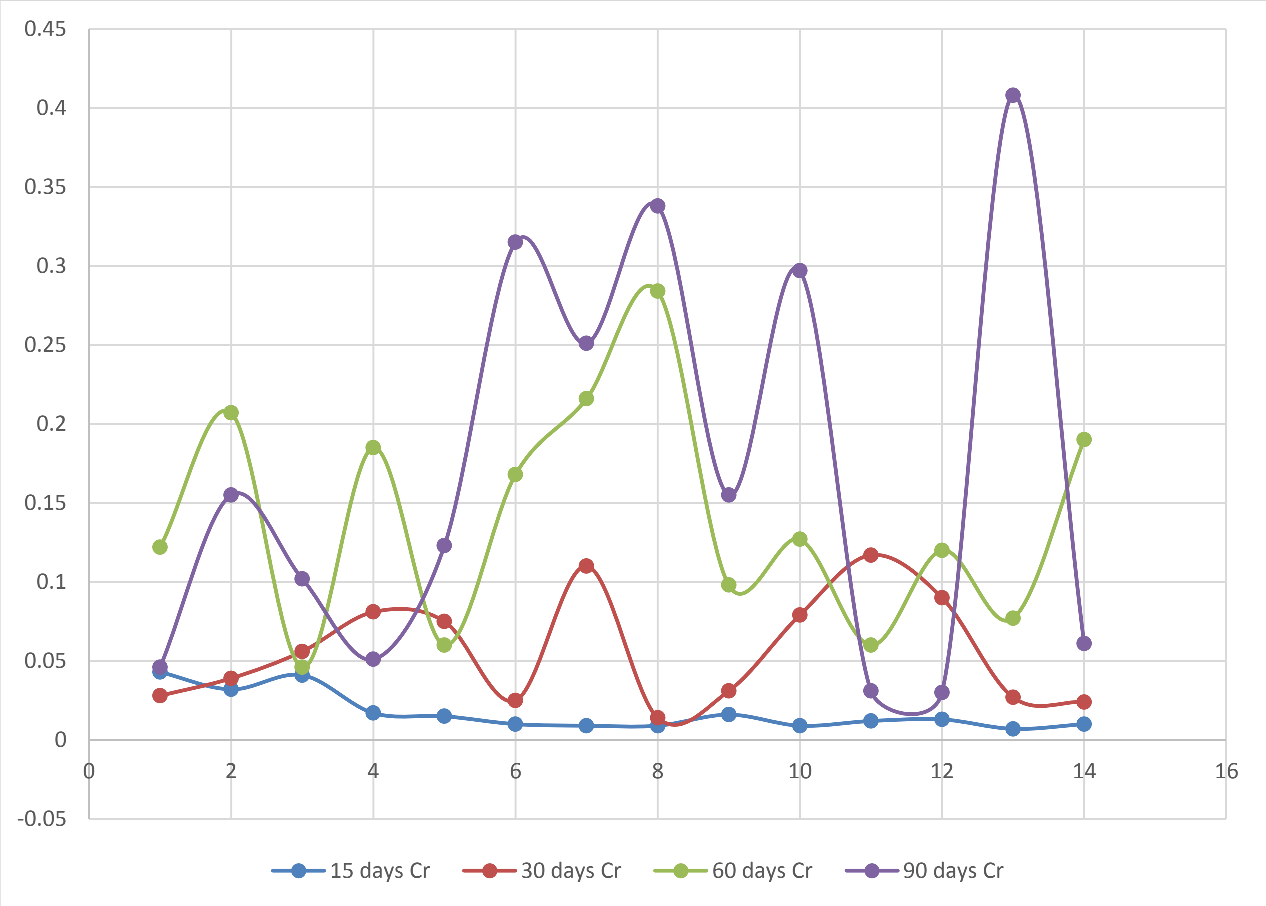
$$BAF = \frac{\text{Concentration of metals in plant}}{\text{Concentration of metals in Soil}}$$

Total accumulation rate is the time taken by the plant to accumulate the metals from the soil.

$$TAR = \frac{\text{Concentration of metals in plant} \times \text{Plant Biomass}}{\text{Plant Biomass} \times \text{Growth in no of days}}$$

Table 5: BAF Chromium on plant saplings after 15 , 30, 60 and 90 days of interval

Plants	15 days Cr	30 days Cr	60 days Cr	90 days Cr
3V	0.043	0.028	0.122	0.046
3L	0.032	0.039	0.207	0.155
4V	0.041	0.056	0.046	0.102
4L	0.017	0.081	0.185	0.051
5V	0.015	0.075	0.060	0.123
5L	0.010	0.025	0.168	0.315
6V	0.009	0.110	0.216	0.251
6L	0.009	0.014	0.284	0.338
7V	0.016	0.031	0.098	0.155
7L	0.009	0.079	0.127	0.297
8V	0.012	0.117	0.060	0.031
8L	0.013	0.090	0.120	0.030
9V	0.007	0.027	0.077	0.408
9L	0.010	0.024	0.190	0.061

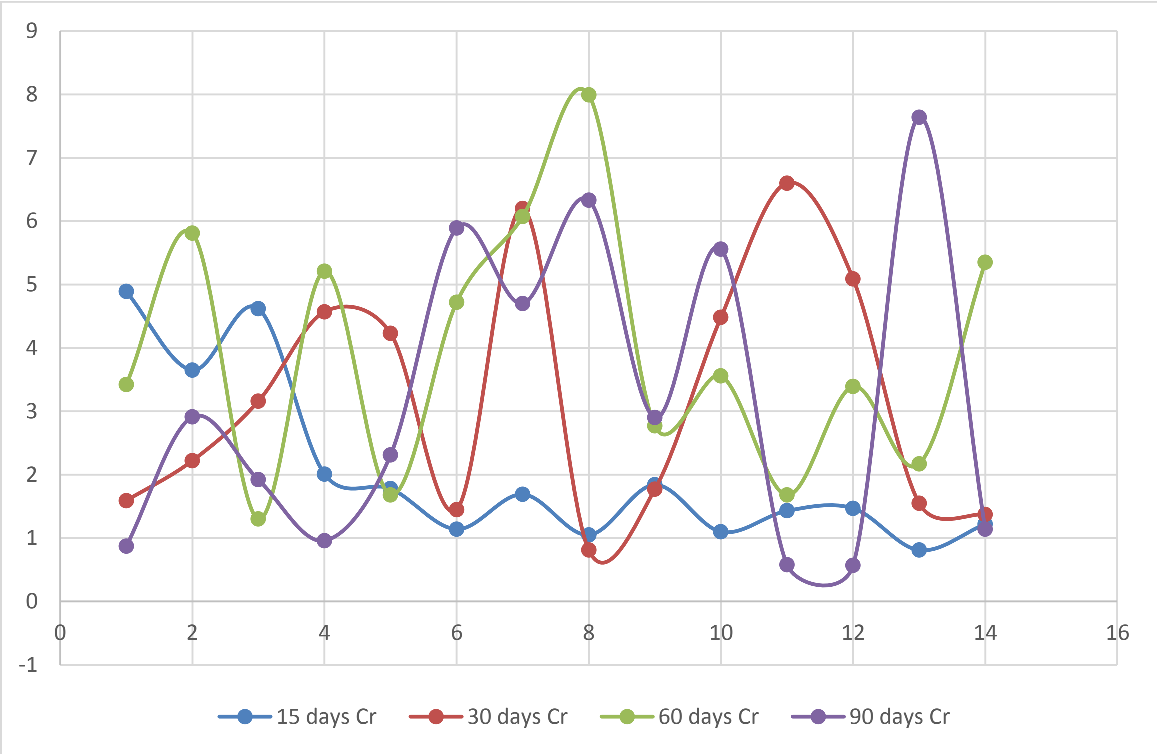


BAF of Plant Saplings after of 15, 30, 60 and 90 Days Treatment

In Table-5; the Treatments denoted as 3,4…..9, whereas V stands for Vetiver and L stands for Lemongrass. The BAF was calculated for 15,30,60 and 90 days of the experiment. Here it has been observed that the highest BAF was obtained for Lemongrass were 0.032, 0.090, 0.284, 0.338 for 15,30,60 and 90 days respectively. Similarly the highest BAF was obtained for Vetiver were 0.043, 0.117, 0.216, 0.408 for 15,30,60 and 90 days respectively.

Table-6: TAR of Chromium on plant saplings after 15, 30, 60 and 90 days of interval

Plants	15 days Cr	30 days Cr	60 days Cr	90 days Cr
3V	4.89	1.59	3.42	0.87
3L	3.65	2.22	5.81	2.91
4V	4.62	3.16	1.30	1.92
4L	2.01	4.57	5.21	0.96
5V	1.78	4.23	1.68	2.31
5L	1.14	1.45	4.72	5.89
6V	1.69	6.2	6.07	4.70
6L	1.05	0.81	7.99	6.33
7V	1.84	1.77	2.77	2.90
7L	1.10	4.48	3.56	5.56
8V	1.43	6.60	1.68	0.58
8L	1.47	5.09	3.39	0.57
9V	0.81	1.55	2.17	7.64
9L	1.22	1.37	5.35	1.14



TAR of Plant Saplings after of 15, 30, 60 and 90 Days Treatment

In Table-6; the Treatments denoted as 3,4…..9, where V stands for Vetiver and L stands for Lemongrass. The TAR was calculated for 15,30,60 and 90 days of the experiment. Here it has been observed that the highest TAR was obtained for Lemongrass were 3.65, 5.09, 7.99, 6.33 for 15,30,60 and 90 days respectively. Similarly the highest TAR was obtained for Vetiver were 4.89, 6.60, 6.07, 7.64 for 15,30,60 and 90 days respectively.

Discussion

Physico- Chemical Analysis of Soil

Soil directly or indirectly affects the agricultural productivity, water quality and the global climate through its function as a medium for plant growth. It acts as a regulator of water flow and nutrient cycling. Soil physical properties determine many key soil processes and management issues. The physico- chemical properties of the garden soil used as control vs. all treatments are presented in Table 1. The degrees of acidity or alkalinity of a soil is a very relevant property affecting many other physico- chemical and biological properties. The pH was observed around 6.9 and the EC value was 10.4 µS/m. The average organic carbon content found to be 0.317 % [Erenoglu, BE. et. al., 2007, Bonet, A. et. al., 1991, Barcelo, J. et. al., 1993, Wong, MHA. and Bradshaw, D. 1982, Brown, JC. et. al., 1956, Ahmad, M. et. al., 2011, Jena, P. et. al., 2016]. The soil having low organic carbon content are possibly due less aeration of soil and decreased rate of oxidation of organic matter as the plants showed growth inhibition at high chromium concentration. Available N, P and K status increased with the increase in Cr concentration in soil which perhaps due to lesser uptake by the plants and their growth inhibition at increasing doses of Cr concentrations [Mohanty, M. and Patra, H. K. 2011, Das, S. et. al., 2014, Han, F.X. et. al.,2004].

Growth Impairment in Response of Cr Stress

The growth parameter studies of lemon grass and Vetiver for 90 days under different treatment of Cr showed significant deterioration in growth with increasing supply of Cr. The fresh and dry weights were very much reduced with the application of high Cr concentration in Lemongrass and vetiver. The toxic effect of Cr on root and shoot length was noteworthy at 100mgkg^{-1} of Cr, whereas at 10mgkg-1of Cr treatments showed better growth of shoot and root length. The possible reason for growth promotion at lower concentration, viz 10 mg kg^{-1} of Cr may be due to the fact that Cr affects Fe availability and/or displacement at the cellular or sub cellular level with improvement of chloroplast ultra structure and plant growth [Hayat, S. et. al., 2012, Mourato, M. et. al., 2012, Tripathi, BN. et. al., 2013, Rastgoo, L. and Alemzadeh, H. 2011, Huang, Y. et. al., 2009, Kishor, PBK. et. al., 2005]. The toxicity of Cr significantly inhibited root vigor, thus restraints roots for delivering nutrients to the shoot region causing inhibition of plant growth and development. Regarding the effect of Cr on plant growth significant synergistic interactions ($p< 0.01$) were observed only between concentration of Cr and length, fresh weight and dry weight of root and shoot of Lemongrass [Hossain, Z. and Komatsu, S. 2012, Mhamdi, A. et. al., 2010, Bhaduri, AM. and Fulekar, MH., 2012].

Chromium Bioavailability in Lemongrass and vetiver plants

Chromium content in plants showed high level differences in accumulation at the end of the experiment. Cr accumulation was more in roots as compared to shoots during plant growth and development. High Cr^{+6} accumulations in root and low accumulation in shoot of the plants is a observed phenomenon in graminaceous plants [Bhaduri, AM. and Fulekar, MH., 2012]. The Total Accumulation Rates (TAR) decreased with increasing concentration of Cr^{+6} (Table-6). Significant positive correlations ($p<0.01$) between the concentration of metal in the plant (whole) body and available metal content in the soil, confirms that the bioaccumulation rate of metal was comparatively higher in treated soil than the control.

Conclusion

In this experiment, Lemongrass and Vetiver has been recommended as a potential plant for alleviation of Cr toxicity from higher chromium contaminated sites. The study revealed that the said plant in Cr contaminated soil produced substantial amounts of biomass, which is directly proportional to uptake of metals. The plants defends them selves from oxidative stress by modification of their various metabolic processes, nutrient uptake and enzymatic reaction mechanisms. At the end of the experiment(90 Days), the highest accumulation of Cr was observed in T9 of Vetiver i.e. 688.08 mg/Kg and T6 of Lemongrass i.e. 570 mg/Kg. Similarly the highest BAF and TAR of Cr was observed in T9 of Vetiver i.e. 0.408, T6 of Lemongrass i.e. 0.338 and T9 of Vetiver i.e. 7.64, T6 of Lemongrass i.e. 6.33 respectively. The outcome of the present experiment using these two species plant will help to prescribe the evolved phytoremediation technology for attenuation of chromium toxicity and its practical application under field conditions. Further, these plants may be recommended in phytostabilisation programmed in adjoining lands of chromites mining sites for its capable root rhizofiltration, phytoaccumulation and phytoremediation ability as observed from different stress tolerances indices.

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