High biomass Chenopodium album L. is a suitable weed for remediation Cd-contaminated soils

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Abstract: Phyextraction is an in situ and cost-effective potential strategy for cleanup contaminated soils. The objective of this study was to find out if halophyte chenopodium album L. can be used for phytoextraction of cadmium from contaminated soils. Consequently, an extensive experiment was carried out to evaluate the phytoextraction ability of one high biomass halophyte. The soils used in the experiment were contaminated with 5, 10, 20, 40, 60 and 100 mg Cd kg−1 soil, in the form of cadmium chloride. Our results indicated that no injury symptoms in chenopodium album L. were observed even on 100 mg kg−1 soil Cd The Cd50 value (Cd at which the yield is reduced by 50%) for Chenopocium album L. evaluate 117 mg Cd kg−1 soils. The Cd transportation from soil to plant was increased by increasing soil cadmium content. At Cd concentration of 100 mg kg−1 which is 100 times more than EPA approved maximum level, only 40 percent reduction observed in wet shoots. Although the average Cd accumulation in shoots was not notably high (40.8 mg kg1 at 100 mg Cd kg-1 soil); its high biomass production resulted to overall high Cd removal (193.8 g ha-1 at 100 mg Cd kg-1 soil). The results were justifying this plant as a potential candidate for Cd phytextraction from the contaminated soil..

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1. Introduction

The accumulation of heavy metal contaminants in the environment is becoming a serious concern due to growing health risks to the public. Exposure to heavy metal contamination has been found to cause kidney damage, liver damage and anemia in low doses, and in high concentrations, heavy metals can be carcinogenic if not fatal (Henry, 2000). Cadmium is a toxic heavy metal for both plants and humans that enter the environment through industrial waste, mill tailings, and landfill run off. This is particularly a grate concern in the developing countries with economic and industrial transitions to keep up with the globalization trend. Although cleanup is necessary to prevent any further discharge of contaminated wastes into the environment, a technology needs to be developed that is cost effective for industry to use. Current technologies resort to soil excavation and either land filling or soil washing, followed by physical or chemical separation of the contaminants.

The cost of soil remediation is highly variable and depends on the contaminants of concern, soil properties, and site conditions and because of the high cost; there is a need for less expensive cleanup technologies (Lasat, 2000). Using plants for environmental remediation is increasing due to their natural capacity to accumulate heavy metals. Plant-based environmental remediation technology, phytoremediation, has been pursued in recent years as an in situ, cost-effective potential strategy for the cleanup of heavy metals from contaminated sites (Salt et al. 1995). phytoremediation avoids dramatic landscape disruption and preserves the ecosystem because it remediates the soil in situ (lasat, 2000). phytoextraction is one of the phytoremediation subdivisions. The selection of phytoextracting species is possibly the single most important factor affecting the extent of metal removal (Pulford and Watson, 2003). Hyperaccumulator plants have the potential to bioconcentrate high metal levels. These plants do not only accumulate high levels of essential micronutrients, but can also absorb significant amounts of nonessential metals, such as Cd. The mechanism of Cd accumulation has not been elucidated. It is possible that the uptake of this metal in roots is via a system involved in the transport of another essential divalent micronutrient, possibly Zn^{2+}. Cadmium is a chemical analogue of the latter, and plants may not be able to differentiate between the two ions (Chaney et al, 1994). However, using hyperaccumulators may be limited by their small size and slow growth. In common nonaccumulator species, low potential for metal bioconcentration is often compensated by the production of significant biomass (Ebbs et al., 1997). In the other hands although the potential for metal extraction is primary important, other criteria, such as ecosystem protection, must be also considered when selecting remediating plants. As a general rule, native species are preferred to exotic plants, which can be invasive and endanger the harmony of the ecosystem.

Iran contains one of the largest collections of halophyte weeds in the world. Some grasses and weeds such as saline grass have high biomass and dense root system in non saline conditions which could be used for phytoextraction. The objective of this study was to find out if halophyte chenopodium album L. can be used as a candidate for cadmium phytoextraction. The rate of metal removal depends upon the biomass harvested and metal concentration in harvested biomass. Halophytes have higher biomass on no saline conditions. So there are two main phytoextraction strategies proposed to clean up toxic metals from soil. The first is the use of metal hyperaccumulator species (Baker et al. 1994) and the second is high biomass producing plants (Solhi et al., 2005). Plant biomass is one important key variables that define the phytoremediation potential of a given plant species. Those plant species that have both high biomass production and can tolerate and accumulate high levels of contaminants of interest are rated to be ideal for remediation. Such combinations are rarely possible since most hyperaccumulators are small and slow growing (Pulford and Watson, 2003).. As an example, Thlaspi caerulescens is generally referred to as a well- known Zn/Cd hyperaccumulator, which can accumulate and tolerate up to 10,000 mg kg^{-1} of Zn and 100 mg kg^{-1} of Cd in shoots (dry matter) without showing any symptoms of toxicity (Escarré et al. 2000). It has been suggested that phytoremediation would rapidly become commercially available if metal-removal properties of hyperaccumulator plants, such as T. caerulescens, could be transferred to high-biomass producing species, such as Indian mustard (Brassica juncea) or maize (Zea mays) (Brown et al., 1995).The other possible alternative is the use of nonaccumulator plants, either high biomass plants that can be easily cultivated using established agronomic practices (Ghosh and Singh 2005; Meers et al. 2005; Solhi et al. 2005). It is commonly known that a significantly high amount of plant biomass can compensate for a relatively low capacity for metal accumulation, resulting in the accumulation of a large amount of heavy metal which has been removed from the soil (lasat2000). The aim of this study is to introduce chenopodium album L. as a high biomass halophyte weed that could be a good candidate for phytoextraction of cadmium from contaminated soil.

2. Material and Methods

An extensive experiment was conducted to evaluate the capacity of halophyte chenopodium album for phytoextracting Cd from the contaminated soils. The soils used in the experiment were contaminated with 5, 10, 20, 40, 60 and 100 mg Cd kg^{-1} soil, in the form of cadmium chloride with four replications. The pots provided with drainage outlets at the bottoms of each one with plates under the pots for giving back the drainage water. Pots with nine kg soil were carefully packed. The in situ balk density of the original uncontaminated soil was 1.33 g/cm3 which were applied to all experimental. Particle size was determined by the hydrometer method. The soil was sandy clay loam (sand 50%, silt 26% and clay 24%) in texture with initial pH 7. 8 (1:2 soil: water), electrical conductivity (EC) 6.71 dS m^{-1} (1:2 soil: water), organic carbon 0.7%, calcium carbonate 7.5% and initial Cd 1.23 mg kg^{-1} (Table 1). The salts ($CdCl_2$) were dissolved in distilled water and then were thoroughly sprayed on all of the 9kg soils for each pot. The appropriate amount of water was added to bring the soil to the estimated field capacity and allowed to equilibrate through 8 weeks on field capacity to complete the reactions between soil and the contaminate. Thereafter, a seedbed was prepared and seeds were carefully seeded in the experimental pots. Recommended agronomic practices were followed and the crops were irrigated by dropped irrigation system to control the drought stress. Whenever the under pots had leaching water, it was given back to the soil so the initial cadmium in each pots was known and the plans was the only source for cadmium removal. After the plants were having four leaves (tertaphyllous), one plant was stayed on each pot because chenopodium album L. has an expanded root system and high biomass. The plants were harvested at maturity growth stages, 120 days after seeding. The plant fresh and dry weights and the transpired water were obtained to evaluate the influence of cadmium on chenopodium album L. growth and produced biomass. After harvesting, the roots were separated from the experimental soils. The collected plant samples were washed with distilled water and dried in oven at 70 C° for 48 hours then it was digested in concentrated HNO_3–$HClO_4$-H_2SO_4 (40-4-1) acids. The Cd concentrations were analyzed by ICP (JY138 ULTRACE) apparatus. Some soil samples were also taken from each pot to measure their total cadmium contents. For these, the procedure proposed by Gupta (2003) was followed, using atomic absorption (SpectrAA-200 –Varian) apparatus. The established statistical experimental design was randomized block design, having seven treatments each with four replicates. After collecting the required data, analysis of variance (ANOVA) was performed, using SPSS software.

Two Phytoextraction efficiencies were calculated which are Bio-concentration factor (BCF) and cadmium uptake (gh-1). The bioconcentration factor refers to heavy metal mobilization into plant tissues and cadmium uptake shows the storage of heavy metal in the aerial plant biomass (McGrath and Zhao 2003). The functions of Bio concentration factor Cd was represented as follows:

BCF = (C-harvested tissue)/(C-soil)

Where C-harvested tissue is the metal concentration in harvested tissues and C-soil is the metal concentration in soil. And chemical properties of soil and water were calculated and collected on table 1.

Table 1. Selected physical and chemical properties of the experimental soil and water (Mean ± SD, n=4)

Soil Parameters	Unit	
Soil texture		Sandy Clay Loam
pH(1:2)		7.8±0.38
Bulk density	(gr/cm^3)	1.334± 0.1
EC(Soil)	(dS/m)	6.71±0.68
Initial Cd (soil)	mg kg^{-1}	1.23±0.011
N	%	0.07±0.002
$CaCO_3$	%	7.5±1.06
OM	%	0.7±0.02
Plant biomass(Shoot DW)	Kg ha^{-1}	4380±640
Applied water Parameters	Unit	
EC	(dS/m)	1.2±0.02
Initial Cd	mg kg−1	0.013±0.00

3. Results

3.1. Growth and yield of plants

The obtained fresh yield of chenopodium album is ranged from 3503 to 2091, g m−2 with Cd levels varying from 1.27 to 94.41 mg kg−1 (Table 2).

Looking at the data given in table 1 indicates that both fresh and dry matters were affected up to of 4.75 mg Cd kg−1 soil. Figure 1 shows the relation between fresh yield and soil Cd concentration. It indicates that the fresh plant of chenopodium album L. decreased by increasing soil Cd content.

Figure 2 shows the transpired water as a function of different soil Cd concentrations. This figure indicates that the relative transpiration decreased by increasing soil Cd content. At Cd concentration of 94.41 mg kg−1 that is 80times more than EPA approved maximum level, plant yield showed only35%, 40% and 48% reduction in relative transpiration ,wet shoot and dry shoot weights, respectively.

Table 2: Initial concentration cadmium (soil), wet and dry matter, BCF,Cd concentration in shoot and Cd removal by shoot of *chenopodium album* L. (n=4)

Applied	Total Cd in soil	Dry shoot (gr/m^2)	Wet shoot (gr/m^2)	Cd con. (mg kg^{-1}) in shoot	BCF	Cd removal by shoot(g
0	1.23	910.8	3503.2	0.32	0.25	2.97
5	4.8	891.7	3137	1.47	0.3	13.17
10	8.9	703.8	3060.6	9.76	1.1	68.75
20	18.65	614.6	2882.1	14.90	0.8	91.58
40	38.25	563.7	2738.4	18.91	0.5	106.63
60	57.35	519.1	2489.1	35.60	0.62	184.80
100	94.41	474.5	2091.4	40.79	0.45	193.57
Mean	31.2	668.3	2843	17.39	.575	94.5
SD	32.6	175	484	22.17	.294	75

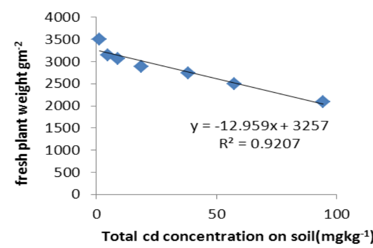

Figure 1. The between fresh plant weight and soil Cd concentration

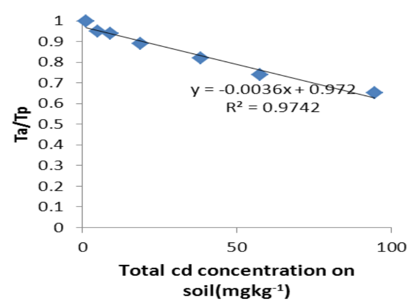

Figure 2. The relation between relative transpiration and soil Cd concentration

The Cd50 (Cd at which the yield is reduced by 50%) value for Chenopocium album was estimated at 117 mg Cd kg−1 soil. For cucumber (Cucumis sativus), a crop earlier proposed for phyto-remediation by An et al, 2004, an effective concentration of Cd for 50% reduction in shoot growth was observed at 88 mg Cd kg−1 soil. No injury symptoms in our study were observed for chenopodium album L. even at 94.4 mg Cd kg−1 soil. Figure 3 shows the relation between Cd concentrations in shoot and Cd concentrations in soil. this figure shows that the Cd transportation from soil to plant is increased by increasing soil cadmium concentration (Fig. 2).

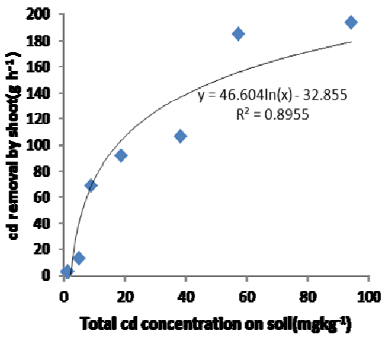

Figure 3 The relation between accumulated Cd
Figure 4 Cd removal by plant shoots (g ha^{-1})

in shoots and soil Cd concentration

Wang et al, 2007 reported increased accumulation of Cd in roots, stem and leaves along with decrease in plant biomass of garlic (Allium sativum), Colocassia esculentum and maize (Zea mays) with increase in soil Cd which our study is also agree with these results.

The average Cd bioconcentration of chenopodium album was 0.57. Zhuang et al (2007) reported Cd bioconcentration of eight Plant Species under field conditions which all of eight plants had higher Cd bioconcentration than chenopodium album. The results from the present study showed that chenopodium album had low cd bioconcentration factor values in all treatments, indicating that this plant had difficulty in mobilizing cd at the root zone. But the goal of the phytoextraction process is to reduce heavy metal concentrations in contaminated soil to acceptable levels within a reasonable time frame. Figure 4 represents the total Cd removal (g ha-1) at different soil Cd concentrations. It is obvious that total Cd removal increased by increasing soil Cd content with Cd level from 1.58 to 94.41 mg kg-1. In 94.41 mg kg-1, which is a high soil Cd contamination, the Cd removal by shoot was 193.6 g ha-1.in one harverst. The rate of cadmium removal from soil during the growth period was equivalent to the area under the curve in Fig. 4.

These Cd-removals are much more than some plants such as Thlaspi (35 ± 11 g ha−1 yr−1) that is being recommended for remediation of Cd-contaminated soils (Greger, 1999). Zhuang et al (2007) reported that R. crispus, could extract 160 gr Cd per hectare when the total cadmium on soil was only 7.2 mg kg-1. However, our results indicate that the Cd removal at 94.41 mg Cd kg-1 soil was 193.6 g ha-1.

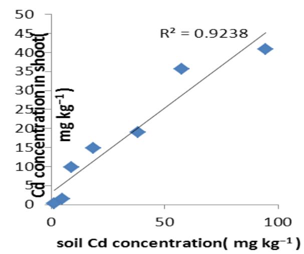

Figure 4 Cd removal by plant shoots (g ha-1)

4. Discussions

Chaney et al. (1994) analyzed the rate of Zn and Cd removal and reached the conclusion that non-accumulator crops will not remove enough metal to support phytoextraction. Despite of this research our study shows that although chenopodium album could not accumulate much cadmium on shoot, it is a good candidate for phytoextraction of cadmium because of high Cadmium removal (193 g ha−1 yr−1 in 100 mg Cd kg-1 soil). It was concluded that although the growth and productivity of chenopodium album L. were affected by cadmium but its tolerance (Cd50 117 mg kg−1) and Cd-removals were comparable with the crops recommended for Cd-phytoextraction. Therefore with the advantage of secondary economically viable use, the halophytes particularly chenopodium album L. have a potential to be raised as alternate crop for phytoextration and other environmental benefits like minimizing the risks of Cd entering into the food chain.

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