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Original Research

Bioaccumulation of Cadium, Copper, Zinc, and Nickel by Weed Species from Municipal Solid Waste Compost

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Abstract

A field experiment was conducted to evaluate the efficiency of native monocotyledonous weed species for heavy metal phytoextraction from municipal solid waste (MSW) compost. Results showed that total contents of cadium (Cd), copper (Cu), and zinc (Zn) in MSW compost generally exceeded the maximum levels indicated in Chinese regulations, except nickel (Ni). The general trend of metal accumulation in plants was Zn>Cu>Ni>Cd and accumulation differences depended on plant species. Except for *Carex tristachya*, the Cd, Cu, and Ni contents in above-ground parts of four other species were within the normal values in plants. Most plants accumulated target metals mostly in the roots. With BCF and TF values >1, *Carex tristachya* displayed some Cd-hyperaccumulative characteristics, being classified as potential species for phytoextraction of Cd from MSW compost. Other species can be considered adequate candidates for metal stabilization and soil conservation.

Keywords: monocotyledonous weeds, MSW compost, phytoextraction, heavy metal

Introduction

With the rise in population and economic development, municipal solid waste (MSW) is being produced massively, especially in developing countries. Chinese cities generate more than 100 million tons of MSW every year [1]. A lot of attention has been paid to the disposal of large volumes of MSW in China. Composting has proved to be an effective way to reduce large quantities of MSW and accelerate the biodegradable components to decompose and stabilize, for completely sustainable recycling [2]. The use of MSW compost on agricultural land enables the recycling of valuable plant nutrients N, P, and K plus micronutrients and organic matter, resulting in beneficial effects on soil properties such as water-holding capacity, aeration and porosity, and plant nutrition [3-5]. However, MSW compost often contains potentially toxic metals that can cause phytotoxicity, soil contamination, and accumulation in plant and animal products [6-8]. Therefore, toxic metals should be cleaned up before MSW compost application on agricultural land.

Phytoextraction, which uses appropriate plants to remove metals from contaminated soils, has gained popularity due to its low cost and comparatively lower damage [9, 10]. Early studies mostly focused on hyperaccumulator plant species and more than 400 species of hyperaccumulators have been documented in the world [11, 12]. Though hyperaccumulators can accumulate exceptionally high quantities of metals, they are not practically used in phytoextraction partly due to the fact that the hyperaccumulator plants are relatively rare, have limited response to various metals, and maintain a slow growth rate [13]. Thus identification of more effective hyperaccumulators is of

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vital importance for successful phytoextraction. According to Robinson et al. [14], a plant used for phytoextraction should be fast growing, easily propagated, and capable of accumulating the target metal. Weed species usually own such inherent properties as strong tolerance to various adverse environmental conditions, fast growth, high reproduction, and biomass that can increase sharply under favourable conditions [15]. Ghosh and Singh [16] indicated that *Ipomoea carnea* was more effective in removing Cd from soil than the hyperaccumulator *Brassica juncea*. *Solanum nigrum*, *Conyza canadensis*, and *Rorippa globosa* were found to possess basic characteristics of a Cd-hyperaccumulator [17, 18]. Muhammad et al. [19] investigated wild plants growing around Pb-Zn sulfide terrain in the Kohistan region of northern Pakistan and found that *Plectranthus rugosus*, *Rumex hastatus*, *Fimbristylis dichotoma*, *Heteropogon conturtus*, and *Myrsine africana* were the best heavy metal accumulators. The main objectives of our research were to:

(1) Estimate the potential of five monocotyledonous weed species for phytoextraction of heavy metals from MSW compost
(2) Assess the contents of several heavy metals (Cu, Cd, Zn, Ni) and their distribution in different plant parts.

Materials and Methods

Description of the Study Area

The experimental site is located on the campus of Tianjin Normal University, China (117º2´E, 39º13´N). The area is characterized by a warm and semi-humid continental monsoon climate. The average annual temperature is 12.3ºC. The warmest and coldest months are July and January, with mean temperatures of 26ºC and -4ºC, respectively. The average annual precipitation is around 550-680 mm, and summer precipitation accounts for about 80% of the annual precipitation. On the basis of the investigations of the yearly averaged sunshine duration from four meterological stations [20], Tianjin has enough sunshine with annual sunshine duration of 2500-2900 hrs. There is no frost in 196-246 d in each year.

MSW compost collected from Tianjin Xiaodian compost plant was spread in the experimental site to a depth of 20 cm. Turfgrass was originally established in the site. Because plenty of weed propagules are widely distributed in the surrounding soil, weed species gradually invaded the experiment site from the outer environment. Weeds in the site experienced germination and growth, and were harvested after their physiological maturity (about 5 months).

Sampling and Analysis

The selected plants commonly found in the local agricultural ecosystem were monocots: *Digitaria sanguinalis*, *Echinochloa crusgalli*, *Carex tristachya*, *Setaria viridis*, and *Cenchrus echinatu*. Once collected, plant samples (3 replicates) were thoroughly washed with tap water and finally rinsed with deionized water, and then divided into roots, stems, and leaves. All the fractions were oven dried at 105ºC for half an hour and then at 80ºC for about 24 hrs to a constant weight. Ground samples (~300 mg) were digested by heating (140-160ºC) in mixed acids of nitric acid and perchloric acid (2:1). After cooling, the digest was diluted to 25 mL and analyzed for heavy metal (Cd, Cu, Zn, Ni) concentrations by inductively coupled plasma-atomic emission spectrometer (ICP-AES). The compost samples were air-dried and crushed and passed through a 2-mm sieve for chemical analysis. Compost pH was measured by glass electrodes in 1:2.5 water extracts [21]. Organic matter content was determined by the method of $K_2Cr_2O_7$-H_2SO_4 oxidation [22]. Total nitrogen content of compost samples was analyzed using Kjeldahl digestion [23]. Available P was measured by sodium hydrogen carbonate solution-Mo-Sb anti spectrophotometric method. Compost samples were wet-digested with a mixture of aqua regia and $HClO_4$. The contents of heavy metals in the digests were determined by ICP-AES as indicated for plant samples.

Statistical Analyses

The data reported in this paper were processed with Microsoft Excel 2003 and SPSS statistical software (SPSS 11.5; Chicago, IL, USA). One-way ANOVA was carried out by considering the different plant species as independent variables at a significant level of $P<0.05$. Ducan's multiple range test was used to compare means.

Results and Discussion

MSW Compost Properties and Metal Concentrations

The MSW compost used as plant culture medium was analyzed. The basic properties were as follows: pH 7.60, organic matter 12.0%, total N 5.10%, available P 77.9 $mg \cdot kg^{-1}$, Cd 1.34 $mg \cdot kg^{-1}$, Cu 304 $mg \cdot kg^{-1}$, Zn 457 $mg \cdot kg^{-1}$, and Ni 26.2 $mg \cdot kg^{-1}$. The compost was slightly alkaline, in agreement with the results of Jordão et al. [21]. The higher pH is attributed to high concentrations of exchangeable bases in compost [24]. Soil pH is a major factor influencing the availability of heavy metals. In most cases, increasing pH declines metal availability [25]. Consistent with other research [21], higher nutrient contents of organic matter and total N were found in compost. Organic matter contains large quantities of plant nutrient that act as a slow-release nutrient storehouse.

When comparing our data with the maximum metal concentrations allowed by Chinese regulations for agricultural soils with pH >7.5 (GB 15618-1995), the total contents of Cd, Cu, and Zn in compost exceeded the allowable limits (0.6, 100, 300 $mg \cdot kg^{-1}$, respectively), while Ni content was below the permissible level (60 $mg \cdot kg^{-1}$). Therefore, the compost was contaminated by Cd (2-fold above the limit), Cu (3-fold above the limit), and Zn (1.5-fold above the limit), and required a remediation process.

Metal Concentrations and Partitioning in Plants

Metal (Cd, Cu, Zn, Ni) concentrations were determined in the roots, stems, and leaves of 5 monocotyledonous weed species growing naturally on the compost and the obtained results are shown in Fig. 1. The Cd concentrations were generally very low for all the investigated plants, which may be partially due to the fact that the level of cadmium in the tested compost was not high enough. These values in plant shoots were below the normal levels in plants (0.1-1 $mg\cdot kg^{-1}$), for Cd [26] only was exceeded by *Carex tristachya* in stems and leaves with a content of 2.28 and 1.63 $mg\cdot kg^{-1}$, respectively.

For Cd and Cu, the highest concentrations in stems and leaves were determined in *Carex tristachya*, and the highest concentrations in roots were found in *Cenchrus echinatus*. The Zn concentrations were generally high for all the tested plants. The highest values for Zn were observed in leaves of *Carex tristachya*, and stems and roots of *Echinochloa crusgalli*. As for Ni, the highest values were determined in all parts of *Carex tristachya*. Additionally, metal distribution in most plants decreased in the following order: root >stem or leaf except for *Carex tristachya*, indicationg lower translocation capacities.

The potential of a plant species for phytoremediation depends on its inherent properties as large yield, rapid growth rate, high metal contents in its aboveground parts, and tolerance to various adverse environmental conditions, including heavy metals [27]. Compared with crops, weed species usually own these characteristics. The tolerance capabilities may be obtained through vacuolar compartmentalization, chelation of metals by some organic acids, and thereby minimization of the loss of biomass [15, 28-30]. The results presented indicate that Cu and Zn concentrations in all the investigated plant species were considerably higher compared to Cd and Ni concentrations. However, the Cd, Cu, and Ni contents in shoots (stems or leaves) were within the normal range (Cd 0.1-1 $mg\cdot kg^{-1}$, Cu 3-20 $mg\cdot kg^{-1}$, Ni 0.1-5 $mg\cdot kg^{-1}$, respectively) for plants [13] except for *Carex tristachya*. The risk of entering into the food chain was highly reduced. The Zn concentrations in stems and leaves were much higher in relation to the normal values of 15-150 $mg\cdot kg^{-1}$ for plants [31], except for *Setaria viridis*.

Metal bioavailability relies not only on the form of the element but also on the plant species. In our study, the content in shoots of *Carex tristachya* of some metals (Cd, Cu, Ni) was significantly higher than other plant species, indicating the occurrence of different mechanisms and its natural adaption to the contaminated compost. Based on the mean concentrations of Cu, Zn, Cd, and Ni in the investigated plants except for *Carex tristachya*, it can be observed that metal contents in stems and leaves were lower compared to the concentration of the same elements in the roots, which is in agreement with the results observed by Antonijević et al. [32]. These results indicate main accumulation of metals in the roots. The mean concents of target metals in plant samples decrease in the following: Zn>Cu>Ni>Cd. This is probably attributed to different metal content in compost, diverse metal uptake mechanisms, and some disparities in their translocation abilities [33].

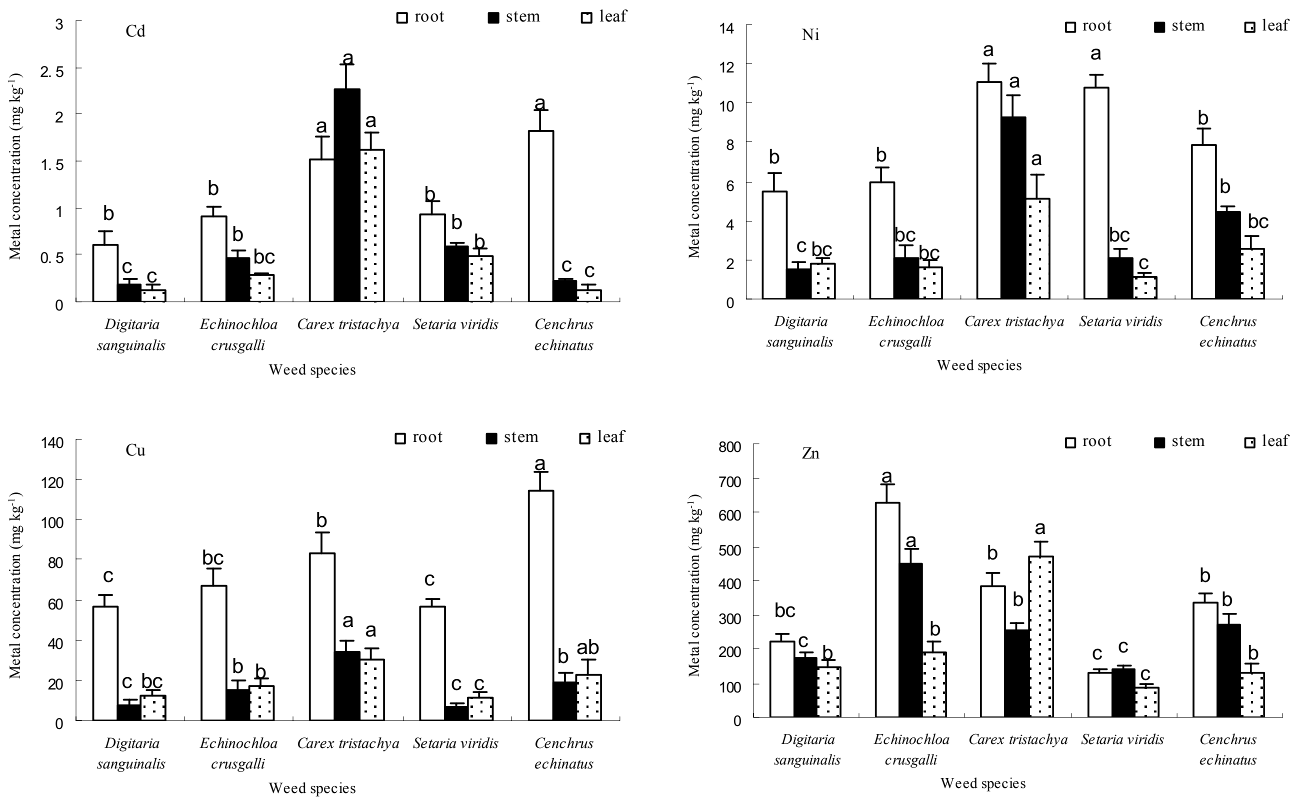

Fig. 1. Metal concentrations and distribution in five monocotyledonous weed species. Error bars represent SD triplicates. Different letters denote significant differences within the same part (P<0.05).

Table 1. Heavy metal bioconcentration factors (BCF) in different parts of five weed species.

Weed species	Different parts	Heavy metal BCF			
		Cd	Cu	Zn	Ni
Digitaria sanguinalis	Root	0.46	0.19	0.48	0.21
	Stem	0.13	0.03	0.38	0.06
	Leaf	0.09	0.04	0.32	0.07
Echinochloa crusgalli	Root	0.68	0.22	1.38	0.23
	Stem	0.34	0.05	0.98	0.08
	Leaf	0.22	0.06	0.42	0.06
Carex tristachya	Root	1.14	0.27	0.84	0.42
	Stem	1.70	0.11	0.56	0.36
	Leaf	1.22	0.10	1.03	0.19
Setaria viridis	Root	0.70	0.19	0.28	0.41
	Stem	0.43	0.02	0.31	0.08
	Leaf	0.36	0.04	0.19	0.04
Cenchrus echinatus	Root	1.35	0.38	0.73	0.30
	Stem	0.17	0.06	0.59	0.17
	Leaf	0.09	0.08	0.28	0.1

Accumulation and Translocation of Metals in Plants

Bioconcentration factor (BCF) and translocation factor (TF) have been used by many researchers to evaluate the ablity of plant to accumulate metal from soil [13, 32]. BCF is defined as the total metal concentration in the plant/total metal concentration in the soil, and TF is defined as the total metal in shoot/total metal in root. Plants can be classified as potential species for phytoextraction if BCF and TF are higher than one, whereas tolerant plants tend to restrict metal transfer from soil to root and root to shoot, and therefore accumulated less in their aboveground biomass [34-36]. Generally speaking, for all the investigated plant species, the BCF values of roots were found to be higher than that of shoots for most metals, implying that metals were easily accumulated in roots (Table 1). Nevertheless, the species *Carex tristachya* was characterized by BCF values higher than 1 of Cd in aerial parts (1.70 for stem and 1.22 for leave, respectively) due to a certain potential for uptake and translocation of Cd. However, BCF values <1 were found for four other plant species. Similar to BCF, the maximum translocation factor (TF=2.56) for Cd was found for *Carex tristachya*, while four other species showed low TF values (Fig. 2). The TF values for all investigated plant species determined for Zn were higher than one, implying that Zn was easily tranfered from roots to shoots. Meanwhile, *Echinochloa crusgalli* and *Cenchrus echinatus* showed a positive potential for Zn and Cd, respectively, and immobilization in the roots (BCF>1). Additionally, some tolerant plants with BCF and TF lower than one also behave as excluders by avoidance, because they have developed mechanisms allowing their growth in highly polluted soils [13]. Thus, considering tolerance, accumulation, BCF, and TF properties together, only *Carex tristachya* indicated Cd-hyperaccumulative characteristics. Wei et al. also reported that some weed species displayed Cd- hyperaccumulative properties, such as *Rorippa globosa*, *Conyza canadensis*, *Taraxacum mongolicum,* and so on [15, 18]. Considering the risk of heavy metals returning to the environment in the process of phytoextraction, plant shoots with accumulated heavy metals should be recovered and disposed of adequately.

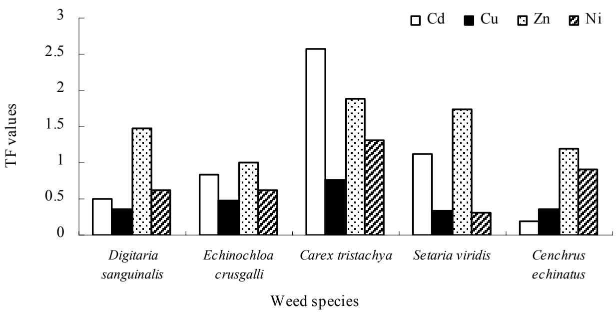

Fig. 2. Heavy metal translocation factor (TF) in five monocotyledonous weed species.

Conclusions

The present research demontrates that total contents of metals in MSW compost generally exceeded the maxium levels indicated in Chinese regulations. The tested indigenous plants wildly growing in the studied area can grow well in contaminated MSW compost. This would be a great advantage if they are used in the revegetation of polluted sites. Based on the examination of five weed species for possible application of phytoextraction, only *Carex tristachya* has the potential for Cd phytoextraction from MSW compost. Other species can be considered adequate candidates for metal stabilization and soil conservation.

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