Pol. J. Environ. Stud. Vol. 24, No. 2 (2015), 887-891

Short Communication

The Absorption and Enrichment Condition of Mercury by Three Plant Species

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Received: 6 December 2013
Accepted: 5 September 2014

Abstract

In this paper we studied the absorption condition of three common plant species, Aloevera var.chinensis, Chlorophytum comosum, and Autumn violet. We compared the enrichment ability of three plant species to lay the foundation for exploring the use of plants to repair mercury-contaminated soils. The amount of mercury uptake by three plant species was determined by cold vapor atomic absorption spectrometry. The results demonstrated that all plant species were able to take up Hg to an extent from a nutrient solution containing 800μg/L Hg and mercury-contaminated soils (total mercury content: 0.15-0.20 μg/g soils). However, the Hg translocation to the stems or leaves wasn't high. The enrichment ability of Chlorophytum comosum was strongest among three plant species.

Keywords: enrichment ability, phytoremediation, repair mercury-contaminated soils

Introduction

There are various sources of environmental pollution by heavy metals. It's necessary to control the content of heavy metals in soils. Currently a lot of research is being conducted on the determination of metals pollution in soils of different areas such as powerplants [1, 2], garbage dumps [3], and metal foundries [4]. Mercury is an element non-essential to human life and extremely harmful to the environment. Since the industrial revolution, substantial quantities of mercury have been released into the environment. For example, the gold mining activities in many developing countries using gold amalgam technology have led to significant mercury pollution in nearby soils and water bodies, and a serious problem of mercury pollution also exists in developed countries [5-9]. Currently mercury-containing waste is increasing in the world. In China, with rapid economic growth and urbanization continually expanding, the mercury-contaminated soils have become a very serious environmental pollution problem nationwide [10]. Investigation results of typical areas indicate that mercury-contaminated soils have caused a significant threat to the water supply, which in turn affects the quality of agricultural products [11, 12]. Mercury (Hg), especially

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in its organic forms (e.g. Methyl mercury (MeHg) and dimethyl mercury (DMeHg)), is a highly toxic pollutant that poses a significant threat to human and wildlife health [13]. Unlike other heavy metals, Hg can be transported over long distances in the atmosphere and scavenged via wet and dry deposition [14, 15]. Therefore, the mercury in soils damages soil and water functions directly, and mercury pollutants, especially methyl mercury, ultimately affects plants, animals, and humans. Also, Beat Frey et al. reported that enhanced mercury (≥3. 2 μg Hg g^{-1} dry soil) deeply affected microbial activities and bacterial community structures in soils [16]. Currently, how to solve the problem of mercury pollution and remediation of polluted soils has become a very urgent task in the world.

Mercury pollution is a global environmental problem [17, 18]. Many countries have invested substantial manpower and material resources to research the removal of mercury in mercury-contaminated soils. Traditional repair methods are soil excavation, landfill, soil cleaning, solidified, and extraction through physical and chemical techniques and so on. These methods have a low efficiency result coupled with high cost and destroy the biological environment of the original soils. However, a new biotechnology-phytoremediation that uses plants for *in-situ* remediation and removal of waste from contaminated soils has obtained wide public acceptance gradually [19, 20]. Compared to the traditional chemical, physical, engineering repair, and other technical methods, it has low investment costs, simple operation, no secondary pollution issues, and potentially significant economic benefits. Phytoremediation can adapt to the environmental requirements better, therefore more and more governments, scientific communities, and business communities are paying attention to it.

For nearly 20 years phytoremediation technology has been widely used for the repair of heavy metal-contaminated soils. Phytoremediation is a biotechnological strategy for remediation of sites polluted with heavy metals and other pollutants, employing plants to extract, sequester, or complex pollutants in terrestrial or aquatic environments [21]. Many developed countries have carried out large-scale experiments, notably the USA and other countries useing hyperaccumulators that have been found for phytoremediation of copper-contaminated soils, plumbum-contaminated soils, zinc-contaminated soils, nickel-contaminated soils, cadmium-contaminated soils, gold-contaminated soils, and arsenic-contaminated soils [22-26]. The results have been positive. However, at present researches about the use of plants to remediate mercury-contaminated soils are few and the hyperaccumulators for mercury haven't been found yet. The aim of the study is to research the absorption condition of mercury in soils by Aloevera var.chinensis, Chlorophytum comosum, and Autumn violet and compare the enrichment ability of three plant species. This would provide a basis for exploring the use of plants to repair mercury-contaminated soils.

Materials and Methods

Plants and Growing Conditions for the Experiment

The test plants were Aloevera var.chinensis, Chlorophytum comosum, and Autumn violet, which were growing well in non-mercury-contaminated soils. The test Aloevera var.chinensis species were divided into three identical groups: one group, No. 1, was cultivated in a 100% Hoagland solution, the second group, No. 2, was cultivated in a 100% Hoagland solution- with 800 μg/L $HgCl_2$; and the third group, No. 3, was cultivated in mercury-contaminated soils (total mercury content: 0.15-0.20 μg/g soils). Chlorophytum comosum species were divided into three identical groups: one group No. 4, was cultivated in 100% Hoagland solution; the second group, No. 5, was cultivated in a 100% Hoagland solution with 800 μg/L $HgCl_2$; and the third group, No. 6, was cultivated in mercury-contaminated soils (total mercury content: 0.15-0.20 μg/g soils). Autumn violet species were divided into three identical groups: one group, No. 7, was cultivated in a 100% Hoagland solution; the second group No. 8, was cultivated in a 100% Hoagland solution with 800μg/L $HgCl_2$; and the third group, No. 9, was cultivated in mercury-contaminated soils (Ttotal mercury content: 0.15-0.20 μg/g soils). The test plants cultivated in solution were placed in locations sheltered from the rain. The temperature was 15ºC-20ºC during the day and 9ºC-12ºC at night.

Design Plan

The aim of this experiment is to study the absorption condition of mercury in soils by Aloevera var.chinensis, Chlorophytum comosum, and Autumn violet and compare the enrichment ability of the three plant species. No. 1, No. 4, and No. 7 plants were compared as background plants. Measurements for the test plants cultivated in solution were made after 7 days. Measurements for the test plants cultivated in mercury-contaminated soils were made after two months.

Experiment

Part of the roots, stems, and leaves of each group of test plants were cut off and cleaned with deionized water. Subsequently, samples were dried to a constant weight naturally. After that, they were crushed and put into appropriate lengths. 0.5 g roots, 0.5 g stems, and 0.5 g leaves of each group were put in 18 150 mL conical flasks and the samples in each were mixed with a little distilled water and shaken with 10 ml nitric acid. They were then put into a bath with a constant temperature set at 60ºC for heating digestion for 10 minutes. Next, a 7-milliliter mixture of sulfuric acid and nitric acid (volume ratio 1:1) was added to each conical flask and shaken well. This caused a violent reaction to occur and after it stopped,

10-milliliter of distilled water and 10-milliliter potassium permanganate solution were added to each conical flask. A small funnel was inserted into each bottle mouth and all conical flasks were put on a low temperature heating plate for 40 minutes, bringing the mixture to near boiling. During the decomposition process, if purple color faded, a potassium permanganate solution was added in order to keep potassium permanganate excess. After 40 minutes the conical flasks were allowed to cool. Before being determined, a hydroxylamine hydrochloride solution was added to each conical flask and shaken until the surplus potassium permanganate and hydrated manganese dioxide in the flask wall faded in color.

Results and Discussion

The amount of mercury in the roots, stems, and leaves of test plants was determined by CVAAS (cold vapor atomic absorption spectrometry, AA-6300 (P/N 206-51800)). All of the three plant species investigated contained small amounts of Hg from the start, and the Hg accumulation increased in roots, stems, and leaves when Hg was added. The results demonstrated that the roots of Aloevera var.chinensis absorbed most mercury among the three plant species (Tables 1-3). The concentration increased most in roots of three plant species, 3940.1-8211.52 times, whereas the increase in stems and leaves of three plant species was only 50.7-242.5, depending on species (Tables 1-3). Also, Cocking et al. and Greger et al. found that Hg concentration increased in various plant parts with increased Hg addition [27, 28].

The data of mercury absorption concentration in stems and leaves of three plant species in 200 ml nutrient solution with 800 μg/L Hg after 7 days and in mercury-contaminated soils (total mercury content: 0.15-0.20 μg/g soils) after two months was used for analysis and comparative mapping (Figs. 1, 2). It can be observed from Figs. 1 and 2 that Hg concentrations in the stems and leaves of Chlorophytum comosum are highest of three plant species.

In order to know the ratio of mercury content in both the stems and roots (leaves and roots) in three plant species in 200 ml nutrient solution with 800μg/L Hg after seven days and in mercury-contaminated soils (total mercury content: 0.15-0.20 μg/g soils) after two months, Eq.(1) and Eq.(2) are calculated as:

Table 1. Mercury concentration in roots, stems, and leaves of Aloevera var.chinensis treated for 7 days, respectively, in 200 ml nutrient solution with 0 or 800μg/L Hg and in mercury-contaminated soils (mean±s tandard deviation; n = 3).

Plant	Hg in Aloevera var.chinensis' /(μg/g)			
	0μg/L Hg	800μg/L Hg	Increase	Mercury-contaminated soils (total mercury content: 0.15-0.20 μg/g soils)
Roots	0.111±0.012	537.756±85.428	4844.6	425.514±21.525
Stems	0.032±0.003	1.901±0.745	59.4	1.502±0.205
Leaves	0.034±0.006	1.854±0.882	54.5	1.233±0.115

Table 2. Mercury concentration in roots, stems and leaves of Chlorophytum comosum treated for 7 days, respectively, in 200 ml nutrient solution with 0 or 800μg/L Hg and in mercury-contaminated soils (mean ±standard deviation; n = 3).

Plant	Hg in Chlorophytum comosum' /(μg/g)			
	0μg/L Hg	800μg/L Hg	Increase	Mercury-contaminated soils (total mercury content: 0.15-0.20 μg/g soils)
Roots	0.116±0.009	457.048±101.242	3940.1	342.215±32.411
Stems	0.015±0.008	4.308±0.741	287.2	2.146±0.445
Leaves	0.008±0.003	4.052±0.452	506.5	2.020±0.101

Table 3. Mercury concentration in roots, stems and leaves of Autumn violet treated for 7 days, respectively, in 200 ml nutrient solution with 0 or 800μg/L Hg and in mercury-contaminated soils (mean±standard deviation; n = 3).

Plant	Hg in Autumn violet /(μg/g)			
	0μg/L Hg	800μg/L Hg	Increase	Mercury-contaminated soils (total mercury content: 0.15-0.20 μg/g soils)
Roots	0.050±0.007	410.576±101.213	8211.52	308.222±15.147
Stems	0.012±0.002	2.910±0.487	242.5	1.642±0.110
Leaves	0.009±0.001	1.756±0.326	195.1	0.854±0.054

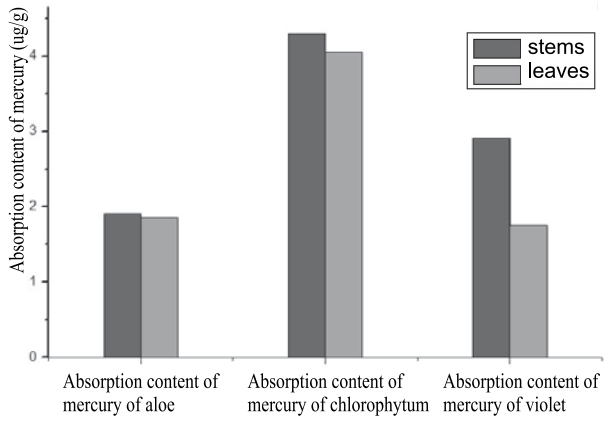

Fig. 1. Comparison chart of mercury absorption concentration in stems and leaves of three plant species in 200 ml nutrient solution with 800μg/L Hg.

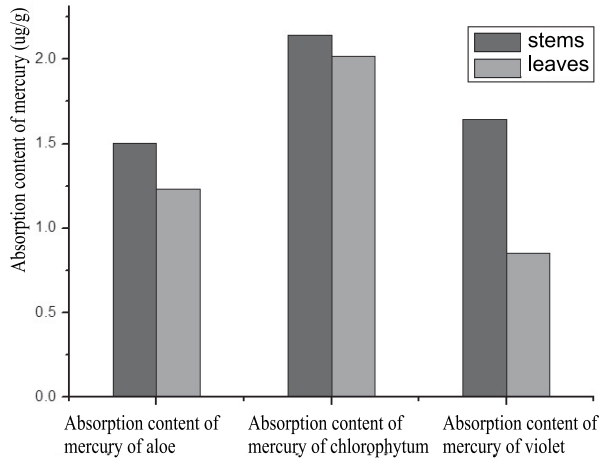

Fig. 2. Comparison chart of mercury absorption concentration in stems and leaves of three plant species in mercury-contaminated soils (total mercury content: 0.15-0.20 μg/g soils).

$$\text{The ratio of mercury content in stems and roots} = [Hg]_{stems} / [Hg]_{roots} \times 100 \quad (1)$$

$$\text{The ratio of mercury content in leaves and roots} = [Hg]_{leaves} / [Hg]_{roots} \times 100 \quad (2)$$

According to the calculation results (Table 4), the ratio of mercury content in both the stems and roots (leaves and roots) (enrichment coefficient) in three plant species in 200 ml nutrient solution with 800μg/L and in mercury-contaminated soils is less than 1% (0.28%-0.94%). So the enrichment coefficient of plants is similar in solution and soils. The enrichment ability of Chlorophytum comosum (0.59%-0.94%) was strongest among three plant species. Also, the enrichment coefficients of willow, pea, wheat, sugar beet, rape, and clover are all less than 1% (0.03%-0.5%) [19]. So the enrichment ability of Chlorophytum comosum is better than willow, pea wheat sugar beet, rape, and clover.

Table 4. Translocation factor of mercury by three plant species.

	Aloevera var. chinensis	Chlorophytum comosum	Autumn violet
The ratio of mercury content in stems and roots (%) (in solution)	0.34±0.01	0.94±0.03	0.71±0.05
The ratio of mercury content in stems and roots (%) (in soils)	0.35±0.01	0.63±0.02	0.53±0.01
The ratio of mercury content in leaves and roots (%) (in solution)	0.34±0.02	0.89±0.02	0.43±0.03
The ratio of mercury content in leaves and roots (%) (in soils)	0.29±0.02	0.59±0.01	0.28±0.02

Conclusion

This study is useful as a basis for exploring the use of plants to repair mercury-contaminated soils. The conclusion drawn from this study is that the enrichment ability of Chlorophytum comosum is strongest among three plant species. Also, the enrichment ability of Chlorophytum comosum is better than willow, pea, wheat, sugar beet, rape, and clover, which is an advantage for exploring the use of Chlorophytum comosum to repair mercury-contaminated soils.

Acknowledgements

We are grateful to Catheriny, Tengtun Xu, Xinda Wu, and Dan Geng for laboratory assistance. Financial support was provided by Chongqing University.

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