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Differences Among Ten Wetland Plant Species in the Tolerances of Lead-polluted Water

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Abstract

Differences among ten wetland plant species in the tolerances of lead (Pb)-polluted water were investigated in constructed wetlands under different water Pb levels. The results presented that the toxic effects of Pb on the biomasses wetland plants varied with plant species, water Pb levels and plant organs. For most of the species, the growth of the wetland plants were not affected significantly ($P > 0.05$) by the water Pb level of 1.5 mg/L. But under the water Pb level of 3.0 mg/L, the plant growth was inhibited greatly for most of the species. In the ten plant species, the biomasses of aboveground parts, underground parts and whole plants were reduced by 3.58% - 22.12% (averagely 11.17%), 3.56% - 32.14% (averagely 15.29%) and 3.58% - 23.71% (averagely 12.06%) respectively by the Pb level of 3.0 mg/L, with significant reductions ($P < 0.05$ or 0.01) in eight species. The results indicate that water Pb level must be considered in the selection of wetland plant species for the treatment of Pb-polluted wastewater. Most of the plant species can be used in the treatment of moderate Pb-polluted water. In the treatment of severe Pb-polluted wastewater, the wetland plant species must be highly tolerant to Pb toxicity, such as *Phragmites communis* and *Alternanthera philoxeroides* in this experiment.

Keywords

Wetland Plant, Lead (Pb), Wastewater, Treatment, Tolerance

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1. Introduction

Lead (Pb) is one of the most important metal contaminants worldwide. Owing to fast development in agriculture and industry, Pb pollution in soil and water environments has been becoming increasingly serious in China [1, 2]. The main sources of Pb pollutants are agricultural, industrial and urban activities [3]. Pb is highly toxic to many organs and systems in human body, such as kidneys, reproduction organs, red blood cells, cardiovascular systems, and central and peripheral nervous system, etc. [4]. Furthermore, the harmful effects of Pb on human body are usually untreatable, irreversible and lifelong [5].

Water pollution by heavy metal is a serious environmental problem, because it threatens aquatic ecosystems and human health. Former studies presented that some vegetables tended to absorb large quantity of Pb from polluted soils and waters, and could accumulate high levels of Pb in the plants [6, 7]. Heavy metals cannot be degraded by biological processes, but they can be removed, mitigated, or immobilized with phytoremediation technology. As an inexpensive biotechnological process, wetland has been researched and used for the treatment of wastewater for more than fifty years [8]. In wetland systems, heavy metals can be removed by many physical, chemical and biological processes, such as being adsorbed by fine particle and organic matter in the sediment, precipitated in the rhizosphere, and taken up by the roots of plants and translocated to the aboveground parts [9]. In constructed wetlands, although sedimentation is recognized as the main process for the removal of heavy metals from wastewater, the uptake and accumulation of

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heavy metals by wetland plants is also an important process [10].

The capacities of wetland plants in uptake and accumulation of heavy metals from wastewater depend on plant's tolerance to metal toxicity, biomass and metal concentration [11]. Our previous study indicated that Cd accumulation abilities of wetland plants correlated positively and significantly ($P < 0.05$) with plant biomasses, specifically in Cd-polluted waters [12]. In this study, the differences among ten wetland plant species in the tolerances of Pb-polluted water were investigated. The results would be useful in the selection of appropriate plant species for the removal of Pb from wastewater with constructed wetland technology.

2. Materials and Methods

2.1. Wetland Construction

Wetlands were constructed under open-air conditions. The wetlands consisted of six chambers, each having 2 m^2 surface area (1 m×2 m). Each chamber was filled with soil to the depth of 25 cm. The soil was obtained from uncontaminated paddy field, and sieved through 5 mm sieve. Pb concentration of the soil was tested with AAS, and Pb concentration of the soil is 33.82 mg/kg (DW). The soil was submerged with water layer of 5 cm for a month before the seedlings of wetland plants were transplanted.

2.2. Wetland Plant Species

The seedlings of ten wetland plant species (seven families) were collected in the wild (Table 1). Three seedlings of similar size (10-20 cm in height) for each plant species were transplanted into each chamber in an even and randomized order.

Table 1. Family and Species of the Wetland Plants Used in This Experiments.

Code Name	Family	Species
A	Gramineae	*Zizania latifolia* (Griseb.) Stapf
B	Gramineae	*Phragmites communis* Trin.
C	Gramineae	*Isachne globosa* (Thunb.) Kuntze
D	Polygonaceae	*Polygonum hydropiper* L.
E	Compositae	*Eclipta prostrata* L.
F	Cyperaceae	*Cyperus iria* L.
G	Cyperaceae	*Fimbristylis miliacea* (L.) Vahl
H	Leguminosae	*Aeschynomene indica* L.
I	Pontederiaceae	*Monochoria vaginalis* (Burm. f.) Presl
J	Amaranthaceae	*Alternanthera philoxeroides* (Mart.) Griseb

2.3. Experimental Design

The artificial wastewater was spiked with Pb at the concentrations of 1.5 and 3.0 mg/L, respectively, to mimic moderate and severe Pb-polluted wastewater [13]. The Pb-polluted solutions were prepared using $PbCl_2$. Each level of Pb-treated wastewater was fed into two of six chambers at three times (160 L for each chamber at each time), i.e. 15th, 22nd and 29th day after the transplanting of plant seedlings. The two chambers receiving non-Pb-treated water (tap water) served as controls. All the chambers were submerged with about 5 cm water layer during the experiment.

2.4. Sample Preparation and Analytical Methods

Fifty days after seedling transplanting, whole wetland plants were harvested. The plants were washed thoroughly with tap water, and then rinsed with deionized water. The plant samples were divided into aboveground parts and underground parts, dried at 70°C to constant weight. The dry plant samples were weighed as biomasses.

Data were analyzed with the statistical package SPSS 19.0. Two significant levels of $P < 0.05$ and 0.01 were used in presenting the results.

3. Results and Discussion

3.1. Effects of Pb on the Biomasses of Aboveground Parts of Different Wetland Plant Species

The biomasses of aboveground parts of ten plant species under different water Pb levels are presented in Table 2. The effects of Pb toxicities on the biomasses of aboveground parts varied with plant species and water Pb levels. On the average, the biomasses of aboveground parts were not significantly changed by 1.5 mg/L water Pb treatment ($P > 0.05$), but they were significantly ($P < 0.01$) reduced by 3.0 mg/L water Pb treatment. Under 1.5 mg/L Pb treatment, the biomasses of aboveground parts did not change significantly ($P > 0.05$) for eight plant species, in the ten plant species, but were reduced significantly ($P < 0.05$) for one species and were increased significantly ($P < 0.05$ for one species. Under 3.0 mg/L Pb treatment, the biomasses of aboveground parts were all decreased for the ten plant species, and the decreasing rates reached significant levels ($P < 0.05$ or 0.01) for eight species.

Table 2. Biomasses of Aboveground Parts of Wetland Plants in Different Pb Levels (g/chamber, DW).

Plant Species	Control	1.5 mg/L Pb Treatment	±% [a]	3.0 mg/L Pb Treatment	±%
A	584.37	607.96	4.04	529.39	-9.41*
B	460.20	468.44	1.79	439.82	-4.43
C	162.52	169.07	4.03	142.44	-12.36**
D	274.24	269.72	-1.65	230.17	-16.07**
E	66.89	62.46	-6.63*	52.64	-21.31**

Plant Species	Control	1.5 mg/L Pb Treatment	±% [a]	3.0 mg/L Pb Treatment	±%
F	130.17	131.12	0.73	105.77	-18.74**
G	178.11	188.55	5.86	153.21	-13.98**
H	242.33	238.42	-1.61	188.73	-22.12**
I	156.50	152.33	-2.67	131.86	-15.75**
J	389.17	422.73	8.62*	375.22	-3.58
Average	264.45	271.08	2.51	234.92	-11.17**

[a] Relative changes of water Pb treatments compared to the control. ±% = ((weight of Pb treatment – weight of control)/weight of control) × 100
*, ** Significant difference between the control and water Pb treatment at $P < 0.05$, 0.01, respectively.

3.2. Effects of Pb on the Biomasses of Underground Parts of Different Wetland Plant Species

The effects of Pb toxicities on the biomasses of underground parts also differed with plant species and water Pb levels (Table 3). Under 1.5 mg/L Pb treatment, the biomasses of underground parts were reduced for nine plant species, with three species reaching significant level ($P < 0.05$), but the biomass of underground part was increased significantly ($P < 0.05$) for one species. As a result, the average reduction rate was small and insignificant ($P > 0.05$). Under 3.0 mg/L Pb treatment, the biomasses of underground parts were highly and significantly decreased ($P < 0.01$) for eight species, and the average decreasing rate was also highly significant ($P < 0.01$).

The toxic effects of Pb on the biomasses of wetland plants were generally higher in underground parts than in aboveground parts.

Table 3. Biomasses of Underground Parts of Wetland Plants in Different Pb Levels (g/chamber, DW).

Plant Species	Control	1.5 mg/L Pb Treatment	±%	3.0 mg/L Pb Treatment	±%
A	321.79	310.88	-3.39	275.13	-14.50**
B	128.42	126.02	-1.87	122.94	-4.27
C	42.34	45.36	7.12*	35.61	-15.91**
D	33.97	31.79	-6.43*	26.50	-22.00**
E	16.53	14.87	-10.01*	11.22	-32.14**
F	35.75	34.36	-3.89	27.03	-24.40**
G	41.69	40.89	-1.93	32.64	-21.72**
H	47.73	46.01	-3.60	32.54	-31.82**
I	23.91	22.42	-6.22	17.93	-25.00**
J	40.69	37.34	-8.22*	39.24	-3.56
Average	73.28	70.99	-3.12	62.08	-15.29**

3.3. Effects of Pb on the Biomasses of Whole Plants of Different Wetland Plant Species

The toxic effects of Pb on the biomasses of whole wetland plants were small and insignificant ($P > 0.05$) under 1.5 mg/L Pb treatment, but were high and significant ($P < 0.01$) under 3.0 mg/L Pb treatment generally (Table 4).

Under 1.5 mg/L Pb treatment, the biomasses of whole wetland plants did not changed significantly ($P > 0.05$) for eight plant species, but increased significantly ($P < 0.05$) for one species and decreased significantly ($P < 0.05$) for one species. Under 3.0 mg/L Pb treatment, the biomasses of whole wetland plants were reduced for all the ten plant species, and the decreasing rates ranged from 3.58% to 23.71%. The reduction rates reached significant level ($P < 0.01$) for eight species.

Table 4. Biomasses of Whole Wetland Plants in Different Water Pb Levels (g/chamber^{-1}, DW).

Plant Species	Control	1.5 mg/L Pb Treatment	±%	3.0 mg/L Pb Treatment	±%
A	906.17	918.84	1.40	804.51	-11.22**
B	588.63	594.46	0.99	562.76	-4.39
C	204.86	214.43	4.67	178.04	-13.09**
D	308.21	301.51	-2.18	256.67	-16.72**
E	83.42	77.33	-7.30*	63.86	-23.45**
F	165.93	165.48	-0.27	132.80	-19.96**
G	219.80	229.44	4.38	185.84	-15.45**
H	290.06	284.43	-1.94	221.28	-23.71**
I	180.41	174.75	-3.14	149.79	-16.97**
J	429.85	460.07	7.03*	414.46	-3.58
Average	337.73	342.07	1.29	297.00	-12.06**

Heavy metal can interfere with many physiological and biochemical processes in plants, such as photosynthesis, respiration, nutrient uptake and metabolism, and the functions of anti-oxidative enzymes. As a result, plant growth and reproduction may be inhibited and plant biomass could be reduced [14]. It was reported that toxic effects of Pb on plants include interference of photosynthesis, antioxidant enzyme activities, and water and nutrient uptake [15, 16]. Lipid membrane damage was observed in Pb-stressed plants of *Brassica napus*, and the toxic effect was associated with MDA and H_2O_2 production in the plants under Pb stress [17].

Our present study showed that toxic effects of Pb on wetland plants differed with plant species, water Pb levels and plant organs. Most of the plant species were tolerable to moderate water Pb pollution (1.5 mg/L). But under severe Pb pollution (3.0 mg/L), the biomasses of most wetland plant species were reduced significantly ($P < 0.05$ or 0.01). The underground parts of the plants were more sensitive to water Pb stress than aboveground parts.

Phytoextraction is recognized as a main process in the technologies of phytoremediation on metal polluted water and soil. However, the effects of phytoextration depend upon plant species to a large extent [18]. The suitable plant species should have several characteristics, such as high biomass, tolerant to the heavy metals in polluted soil or water, fast growth in polluted environment, easy harvesting, etc. [19]. At present, some plant species has been reported possessing some of the criteria, due to their abilities to detoxify metal stress through the synthesis of phytochelation (PCs) in plants, and by maintaining or enhancing the activities of antioxidant enzymes [20, 21].

Our present research indicates that most of the plant species can be used in the treatment of moderate Pb-polluted water. But only few species are suitable for the treatment of heavy Pb-polluted wastewater.

4. Conclusions

The tolerances of wetland plants to Pb toxicities varied with plant species, water Pb levels and plant organs. Under the Pb level of 1.5 mg/L (moderate Pb pollution), the growth of the wetland plants were not affected generally. For most of the species, the biomasses of aboveground parts (nine of ten species), underground parts (seven of ten species) and whole plants (nine of ten species) did not change significantly ($P > 0.05$). But under the Pb level of 3.0 mg/L (severe Pb pollution), the growth of the wetland plants were inhibited greatly for most of the plant species. In the ten plant species, the biomasses of aboveground parts, underground parts and whole plants were reduced by 3.58% - 22.12% (averagely 11.17%), 3.56% - 32.14% (averagely 15.29%) and 3.58% - 23.71% (averagely 12.06%) respectively. The reduction rates reached significant levels ($P < 0.05$ or 0.01) for eight species. Therefore, in the selection of wetland plant species for the treatment of Pb-polluted wastewater, Pb level of the water must be considered. Most of the plant species can be used in the treatment of moderate Pb-polluted water. But in the treatment of severe Pb-polluted wastewater, highly tolerant plant species must be selected, such as *Phragmites communis* and *Alternanthera philoxeroides* in this experiment.

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