Lead Uptake by Roots of Four Turfgrass Species in Hydroponic Cultures

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Additional index words: buffalograss, centipedegrass, Spartina patens, tall fescue

Abstract. Turfgrass, which is widely grown and produces a large amount of biomass, could act as a sink for industrial pollutants in urban and suburban regions. Little research has been conducted regarding heavy metal uptake by turfgrasses. The objective of this study was to evaluate root uptake of lead (Pb) in four turfgrass species. Grasses were grown hydroponically in solutions containing from 0 to 450 mg·L–1 Pb, at either pH 4.5 or 5.5, for 4 or 8 days. A significant quadratic relation existed between Pb accumulation in roots and solution Pb concentration within the tested range. The maximum Pb accumulation in roots of the four species was in the range of 20 mg·g–1 dry root weight. Tall fescue (Festuca arundinacea Schreb.) and Spartina patens survived at 450 mg·L–1 Pb solution without showing obvious damage while centipedegrass (Eremochloa ophiuroides (Munro) Hack.) and buffalograss (Buchloe dactyloides (Nutt.) Engelm.). deteriorated or died at this concentration. This study showed that turfgrass plants can absorb heavy metals efficiently and tolerate high Pb concentration in hydroponic solutions and thus may have a potential use in environmental remediation as a biological extractor of lead.

Release of pollutant metals to the biosphere has increased dramatically during the past century (Nriagu, 1979). Among the toxic metal contaminants, lead (Pb) poses a major concern because of its extensive distribution and the substantial environmental and human health problems it causes (Cunningham and Berti, 1993). Lead pollution has resulted from industrial and mining activities, as well as the use of lead-containing substances, such as paints, gasoline, explosives, and water pipes (Huang et al., 1997). Remediation of toxic metals, including Pb, and other pollutants has been an important research subject for environmental studies. Metal remediation has also become a multibillion-dollar industry in the United States, usually relying on engineering-based technologies, such as isolation and containment, and decontamination by physical, chemical, or biological treatments (Cunningham and Berti, 1993). Over the past decade, phytoremediation, defined as remediation of pollutants by using green plants, has emerged as a new strategy with great potential. Phytoremediation may involve metal absorption from the soil and transportation to the harvestable parts of the plants (phytoextraction), absorption and concentration of toxic metals in plant roots from polluted effluents (rhizofiltration), and reduction of heavy metal mobility in the soil by plants (phytosanitization) (Sait et al., 1995, 1997). Phytoremediation studies of Pb-contaminated soil have shown that some plants can accumulate Pb at high levels (Huang and Cunningham, 1996; Qureshi et al., 1985). Moreover, Pb extraction was greatly enhanced by treating the contaminated soil with synthetic chelates (Huang et al., 1997).

Turfgrass is often planted as a major vegetative groundcover in many landscapes, especially in urban regions. The large acreage of turfgrass grown (e.g., 30 million acres in the United States as estimated in 1990 (Emmons, 1995)) and the high volume of biomass it produces make turfgrass potentially suitable for urban environmental remediation. Turfgrass plants may contain Pb and other heavy metals in excess of 1 mg·kg–1 of their dry matter when grown in typical non-polluted soils (Jones et al., 1973). The heavy metal content of tall fescue (Festuca arundinacea Schreb.) grown with sewage sludge was also reported (Boswell, 1973; King, 1981). However, little research has been performed to study the tolerance of turfgrasses to high levels of heavy metals and the maximum possible accumulation in their tissues (Dushenkov et al., 1995; Li et al., 2000). The long-term objective of this research is to study the potential role that turfgrasses might play in environmental remediation of metal-contaminated soils and the mechanism behind it. As the first step towards this goal, root accumulation of Pb in four turfgrass species and its effect on plant performance were studied.

Materials and Methods

Plant materials and experimental conditions. Plants of centipedegrass (Eremochloa ophiuroides (Munro) Hack. ‘Common’), buffalograss (Buchloe dactyloides (Nutt.) Engelm. ‘Common’), tall fescue (Festuca arundinacea Schreb. ‘Houndog V’) and Spartina patens (‘Common’) were grown in a loam soil at the experimental station of Nankai Univ. (Tianjin, China). Spartina patens is used as a vegetative groundcover species on saline soils. Plants =15 cm in height were collected, rinsed with deionized water several times to remove attached soil, and used for the experiments. The plants were then cultivated hydroponically in Pb-containing solutions. Each hydroponic unit consisted of a glass jar (7 cm in diameter × 12 cm in height) containing 200 mL solution with varying Pb concentrations and pH values. The Pb source used for the experiments was Pb(NO3)2 (purity >99%; Tianjin Third Chemical Plant, Tianjin, China). The solutions were made with Pb-free deionized water. The pH of the solutions was adjusted with 0.1 or 0.1 m NaOH to achieve a final pH of 4.5 or 5.5. To be on a comparable basis, plants with 0.5 ± 0.1 g dry root weight (as predetermined) were selected as an experimental unit for each jar. The plant roots were completely immersed in the solutions. The total volume of the solution was kept constant by adding deionized water every day to compensate for water loss through evaporation and transpiration. The plants were incubated at a temperature range of 26 to 30 °C with a 14-h day/10-h dark photoperiod and 85% relative humidity, under natural light conditions (with light intensity in the range of 500–1000 µmol·m–2·s–1) for 4 or 8 days. The plants were then incubated before sample collection for Pb analysis.

Experimental design and data analysis. To study the effect of Pb concentration (0, 200, and 400 mg·L–1), pH value of the cultivating solution (pH 4.5 and 5.5), and duration of growth (4 and 8 d) on Pb accumulation in roots of three turfgrass species (centipedegrass, buffalograss, and tall fescue), a completely randomized design with three replications was used for Experiment A (Table 1). The lower pHs were chosen because Pb is more available to plants in soil with lower pH (Cunningham and Berti, 1993).

In Experiment B, the relationship between Pb accumulation in roots and Pb concentration in the cultivating solution was investigated. Three turfgrass species (centipedegrass, buffalograss, and S. patens) were used for the experiment. The Pb concentrations tested were from 0 to 450 mg·L–1 in 50 mg·L–1 increments. The Pb solution was adjusted to pH 5.0 and the
plants were cultivated under the same conditions as in Experiment A for 8 d.

ANOVA analysis and F tests were performed in Experiment A while regression analysis (Du, 1999) was carried out for Experiment B. All statistical analyses were performed using SAS statistics software (SAS Institute, 1985).

Sample collection and Pb content analysis.
At the end of the growth period, plants were removed from the Pb solutions for analysis and were rinsed with deionized water for 5 min. Plant roots were then sliced into small fragments and were oven-dried at 80 °C for 48 h. The dry weight of the roots of each sample was determined and the dried roots were then ashed at 550 °C for 6 h. The ash of each sample was dissolved in 5 mL 1 M HNO₃ and diluted to 50 mL with deionized water in a volumetric flask. The Pb content of the samples was determined using a Hitachi 180-80 Polarized Zeeman Atomic Absorption Spectrometer (Hitachi Ltd., Tokyo) with the following parameters: wavelength 283.3 nm, lamp current 7.5 mA, slit 1.3 nm, burner standard type, burner height 15.0, fuel C₂H₂ 2.5 L·min⁻¹, oxidant air 9.4 L·min⁻¹, analytical mode FAAS (CON), measurement mode ‘Integrated (5 s), equation type linear fit, background/ZAA ON. The correlation coefficient of the standard curve within the range of 0–15 mg·L⁻¹ Pb was 0.999 and the standard deviation of nine assays was 0.027 with a CV of 0.33%.

Table 1. ANOVA summary table for Expt. A: accumulation of lead in turfgrass roots.

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species (S)</td>
<td>405.94</td>
<td>2</td>
<td>202.97</td>
<td>15.55</td>
<td>0.0001**</td>
</tr>
<tr>
<td>Pb Concn (C)</td>
<td>7590.92</td>
<td>2</td>
<td>3795.46</td>
<td>27.76</td>
<td>0.0045**</td>
</tr>
<tr>
<td>pH</td>
<td>0.03</td>
<td>1</td>
<td>0.03</td>
<td>0.01</td>
<td>0.9341</td>
</tr>
<tr>
<td>Cultivation days (D)</td>
<td>209.89</td>
<td>1</td>
<td>209.89</td>
<td>12.69</td>
<td>0.0706</td>
</tr>
<tr>
<td>Replication</td>
<td>26.63</td>
<td>2</td>
<td>13.32</td>
<td>1.02</td>
<td>0.3659</td>
</tr>
<tr>
<td>S x C</td>
<td>546.88</td>
<td>4</td>
<td>136.72</td>
<td>10.47</td>
<td>0.0001**</td>
</tr>
<tr>
<td>S x pH</td>
<td>7.35</td>
<td>2</td>
<td>3.68</td>
<td>0.28</td>
<td>0.7554</td>
</tr>
<tr>
<td>S x D</td>
<td>33.09</td>
<td>2</td>
<td>16.54</td>
<td>1.27</td>
<td>0.2880</td>
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<tr>
<td>C x pH</td>
<td>23.44</td>
<td>2</td>
<td>11.72</td>
<td>1.36</td>
<td>0.3550</td>
</tr>
<tr>
<td>C x D</td>
<td>114.41</td>
<td>2</td>
<td>57.20</td>
<td>4.02</td>
<td>0.1103</td>
</tr>
<tr>
<td>pH x D</td>
<td>5.95</td>
<td>1</td>
<td>5.95</td>
<td>1.65</td>
<td>0.3280</td>
</tr>
<tr>
<td>S x C x pH</td>
<td>34.56</td>
<td>4</td>
<td>8.64</td>
<td>0.66</td>
<td>0.6207</td>
</tr>
<tr>
<td>S x C x D</td>
<td>56.88</td>
<td>4</td>
<td>14.22</td>
<td>1.09</td>
<td>0.3687</td>
</tr>
<tr>
<td>S x pH x D</td>
<td>7.22</td>
<td>2</td>
<td>3.61</td>
<td>0.28</td>
<td>0.7593</td>
</tr>
<tr>
<td>C x pH x D</td>
<td>5.90</td>
<td>2</td>
<td>2.95</td>
<td>0.75</td>
<td>0.5303</td>
</tr>
<tr>
<td>S x C x pH x D</td>
<td>15.81</td>
<td>4</td>
<td>3.95</td>
<td>0.30</td>
<td>0.8752</td>
</tr>
<tr>
<td>Error</td>
<td>913.96</td>
<td>70</td>
<td>13.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9998.86</td>
<td>107</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significantly different at *P* < 0.01 by F test.

**Results**

Effects of species, Pb concentration, pH and cultivation period. Three turfgrass species, centipedegrass, buffalograss, and tall fescue, were examined for the effects of Pb uptake on various factors and root accumulation in Experiment A. The Pb content in roots for the various treatments are presented in Fig. 1. ANOVA analysis and F tests of the data (Table 1) indicated that species, Pb concentra-

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Fig. 1. Pb absorption in roots of three turfgrass species (centipedegrass, buffalograss, and tall fescue) as the function of Pb concentration, pH of the cultivating solution, and the cultivation period.

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tion, and the interaction between species and Pb concentration had highly significant effects ($P < 0.01$) on Pb accumulation in roots. The pH levels and all other possible interactions did not influence Pb accumulation in roots. Lead accumulation in roots did not vary significantly in response to the 200 and 400 mg L$^{-1}$ treatments for centipedegrass and buffalograss, whereas tall fescue accumulated significantly more Pb at a solution concentration of 400 mg L$^{-1}$ compared to 200 mg L$^{-1}$ Pb (Fig. 1).

**Pb accumulation in roots as a function of Pb concentration of the cultivating solution.** In Experiment B, regression analysis revealed differences at the rate of Pb uptake and maximum Pb accumulation among the turfgrass species. The relationship between Pb accumulation in roots and Pb concentration in the culture solutions within the tested range can be best expressed as a quadratic regression curve for each of the three species analyzed, respectively (Fig. 2).

Based on the regression analysis, maximum Pb accumulation in centipedegrass was 20.71 mg g$^{-1}$ dry root weight, which occurred when the Pb concentration in the cultivation solution was about 415 mg L$^{-1}$. These two values for buffalograss were about 21.55 mg g$^{-1}$ and 354 mg L$^{-1}$, respectively. Lead accumulation in *S. patens* did not reach an obvious maximum value within the experimental range of Pb concentration. The regression model suggests that it may have a higher accumulation of 25.5 mg g$^{-1}$ dry root weight when the Pb concentration in the cultivating solution is 461 mg L$^{-1}$. Statistical analysis indicated that there was a highly significant correlation between Pb accumulation in roots and Pb concentration in the cultivating solutions ($P < 0.01$, data not shown) for all three species tested.

**Effects of Pb on growth of the four turfgrass species.** *Spartina patens* and tall fescue displayed the best Pb tolerance in the experiments. They appeared darker green and healthier, and developed substantial new roots in 50 mg L$^{-1}$ Pb solution. Even when Pb concentration reached 450 mg L$^{-1}$, the plants still developed new roots and leaves, and showed no obvious chlorosis, withering, or root deterioration. Among the species tested, centipedegrass displayed the least tolerance to Pb toxicity. When the Pb solution concentration reached 100 mg L$^{-1}$, centipedegrass developed no new roots. Plants began to show chlorosis within 1 d of growth in 150 mg L$^{-1}$ Pb solution. In 450 mg L$^{-1}$ Pb solution, the plants turned yellow and the roots deteriorated. Buffalograss showed medium Pb tolerance among the four. Buffalograss continued to develop new roots when Pb concentrations were at or below 200 mg L$^{-1}$. However, when Pb concentration reached 250 mg L$^{-1}$ or higher, new root development stopped, chlorosis occurred, and some leaves started withering. Buffalograss plants died when the solution Pb content was maintained at 450 mg L$^{-1}$ Pb.

**Discussion**

Turfgrasses are important landscape plants used to beautify and protect our environment.

HO**RTSCIENCE, VOL. 38(4), JULY 2003**
Recent reports suggested that turfgrasses can facilitate degradation of organic pollutants (Briggs et al., 1999, Hosler and Drake, 1999; Fiorenza et al., 2000; Qiu et al., 1994, 1997; Epuri and Sorensen, 1997; Fetterolf et al., 1999). However, little research has been performed to evaluate turfgrass tolerance to another major group of pollutants, heavy metals, and its capacity to absorb these metals. As a first step, we characterized Pb accumulation in roots of four turfgrass species, and its effect on apparent plant health. We observed that some turfgrasses have the capacity to accumulate substantial amounts of Pb in their roots, and that some turf species are more tolerant to Pb than others. In our experiments, S. patens and tall fescue tolerated higher Pb concentrations and thus could be choices for planting in Pb contaminated soil.

There was a profound discrepancy in Pb accumulation in turfgrass roots in this study compared to results published by Dushenkov et al. (1995). Maximum Pb accumulations were in the range of 20–30 mg·g⁻¹ dry root weight in these experiments (or 2% to 3%) compared to about 100 mg·g⁻¹ (or 10%) in weight in these experiments (or 2% to 3%) and its capacity to absorb these metals. As another major group of pollutants, heavy metals and organic pollutants from the environment, Genetically engineered turfgrass plants may further enhance their ability to facilitate degradation of organic pollutants in a solution of 400 mg·L⁻¹ while the amount of Pb in each hydroponic unit was half of solution aeration in this research may have inhibited Pb uptake to certain extent.

Because plants can help remove heavy metals and organic pollutants from the environment, Sandermann (1994) called plants the “green liver” of our environment. Our results indicate that turfgrasses can accumulate substantial amounts of heavy metals and thus could be a major component of such a “green liver,” particularly in urban and suburban regions in the world. Genetically engineered turfgrass plants may further enhance their ability to perform this function (Rugh et al., 1996). However, very little is known regarding the uptake, compartmentalization, and translocation of heavy metals in turfgrasses and the associated mechanisms, or the mechanism of turfgrass degradation of toxic organics. If turfgrass cultivars that translocate substantial amounts of heavy metals to the shoots can be identified as in Brassica juncea (Nanda Kumar et al., 1995), clipping removal of turfgrass can be an efficient way to remove heavy metals from the polluted soil. Research in this area will help further understanding of the interaction between turfgrass and toxic xenobiotics and application of turfgrass in environmental remediation.

**Literature Cited**


