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Perennial Plants in the Phytoremediation of Lead-contaminated Soils

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Abstract: In this experiment, three local perennial plant species, *Alternanthera philoxeroides*, *Sanvitalia procumbens* and *Portulaca grandiflora*, were examined for their ability to uptake lead from lead contaminated soils (75 mg kg^{-1}). Lead concentration in soil under all treatments decreased between 30-80% (62.61-23.18 mg kg^{-1}) when compared to the control (75 mg kg^{-1}). In all treatments, lead accumulation in the plants was higher on day 45 than what was found on days 55 and 65. Among these three species, *A. philoxeroides* showed a greater potential for lead accumulation than *P. granaiflora* and. *S. procumbens*. On day 45, *A. philoxeroides* showed significant differences in lead accumulation (29.99%) compared to that from *P. granaiflora* (13.03%) and *S. procumbens* (16.44%). Even though the amount of lead extracted by these three plants was small, the results showed that *A. philoxeroides* had the ability to extract an approximately 1.3-1.8 times greater amount than *P. grandiflora* and *S. procumbens*. Phytoremediation technology is environmentally friendly and cost-effective; *A. philoxeroides* may be a practicable alternative for protecting the soil in Thailand from leaching lead.

Key words: Perennial plant, *A. philoxeroides*, *S. procumbens*, *P. grandiflora*

INTRODUCTION

In Thailand, large areas of soil, air and water are contaminated with Lead (Pb). This pollution is a result of human activity and involves the use of Pb in gasoline additives, paints, batteries and pesticides. Pb-contamination in the environment is found in an insoluble form, and the toxic metals pose serious human health problems, namely, brain damage and retardation. Phytoremediation is the use of plants to clean up a contamination from soils, sediments and water. Presently, phytoremediation is one effective and affordable technological solution used to extract or remove inactive metals and metal pollutants from contaminated soils (Chen *et al*., 2004). This technology is environmentally friendly and potentially cost-effective (Boyajian and Carreira, 1997). Plants with exceptional metal-accumulating capacity are known as hyperaccumulator plants. Many species of plants have been successful in absorbing contaminants such as lead, cadmium, chromium, arsenic and various radionuclides from soils (Baker *et al*., 2000; Chrysafopoulou *et al*., 2005; Marchiol *et al*., 2004). Garbisu and Alkorta (2001) reviewed one phytoremediation category, phytoextraction, for its ability to remove heavy metals from soil using its ability to uptake metals which are essential for plant growth (Fe, Mn, Zn, Cu, Mg, Mo and Ni). Some metals with no known biological functions (Cd, Cr, Pb, Co, Ag, Se and Hg) can be accumulated (Baker and Brooks, 1989; Raskin *et al*., 1994).

The experiment outlined in this research was undertaken to study phytoextraction of the perennial plants Creeping Zinnia (*Sanvitalia procumbens*), Moss rose (*Portulaca grandiflora*) and Alligator weed (*Alternanthera philoxeroides*). Edible plants, such as *A. philoxeroides* grow well on sewage sludge, and have been used for the removal of lead and mercury from polluted waters. *A. philoxeroides* is an annual or perennial herb with prostrate ascending stems and 10 m long stolon and rooting at the nodes. This plant can form dense floating or rooted mats in aquatic and seasonally inundated land. Sanvitalia (*S. procumbens*) is a shrub (4-6 inch height) and a fast-growing plant. It has a massive and complex root system, but the roots distribute

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vastly near the soil surface. Its flower is yellow gold similar to a daisy and it is native to Southern America and Mexico. Rose moss (*P. grandiflora*) is native to South America. It is a perennial herb and is often cultivated as a perennial plant. It has thickened taproot. Stems occur at 20 cm long and its flowers can be found in various colors (Cutter, 1978).

The three perennial plants are high growth rate plants with massive root systems and environmentally tolerant; they are widely found in Thailand. Owing to their beneficial characteristics, we believe these three plants will uptake lead from the soil and store it in their tissues. Therefore, the purpose of this study was to asses the feasibility of these plants for use in the phytoremediation of Pb-contaminated soils (75 mg kg^{-1}) and evaluate each plant's potential to react on the contaminated soil. Moreover, the factors affecting lead assimilation, such as, soil pH and plant age were examined.

MATERIALS AND METHODS

Soil preparation: The soil was collected from Mahasarakham Province in Northeast Thailand. 1.5 inches of the top layer of organic matter was removed and the soil was air-dried and sieved to 150 microns. The dried soil was stored until used.

Contaminated soil preparation: 100 mg L^{-1} of lead solution was added to the non-contaminate dried soil until the amount of 75 mg of lead was present in 1 kg of soil sample.

Specimen plants: *S. procumbens*, *P. grandiflora* and *A. philoxeroides* were used in the experiments. 150 seedlings of these plants were grown in non-contaminated soil which containing 200 mg kg^{-1} of biological fertilizer and 150 mg kg^{-1} of N, P and K and tap watering throughout. After 30 days of planting, healthy plants were selected and used as the specimen plants.

Lead solution: A lead solution was prepared at the concentration of 100 mg L^{-1} by using the standard lead solution.

Block preparation: Soil was loosened one time before the specimen plants were cultivated. Specimen plants were cultivated in a Randomized Complete Block Design of 12 blocks with three replications of each treatment. Each block size was 1.2×1.2 m and there were 20 plants in each block. Specimen plants were grown with 20 and 20 cm row to row and line to line spacing, respectively. This study was carried out between October 2004 to January 2005 at Mahasarakham University, Mahasarakham Province in Northeast Thailand.

Treatment design: Four treatments (3 blocks/ treatment) were evaluated in this experiment as follows:

T 1: Pb-contaminated soils (75 mg kg^{-1}) + 0.9 kg $block^{-1}$ of NPK 15:15:15 + without specimen plant

T 2: Pb-contaminated soils (75 mg kg^{-1}) + 0.9 kg $block^{-1}$ of NPK 15:15:15 + *S. procumbens*

T 3: Pb-contaminated soils (75 mg kg^{-1}) + 0.9 kg $block^{-1}$ of NPK 15:15:15 + *P. grandiflora*

T 4: Pb-contaminated soils (75 mg kg^{-1}) + 0.9 kg $block^{-1}$ of NPK 15:15:15 + *A. philoxeroides*

Chemical fertilizer was incorporated in soils prior to loosening. Twenty specimen plants in a block from each treatment were harvested on day 45, 55 and 65 after cultivation.

Analysis: The collected specimen plants and soil on days 45, 55 and 65 were determined using the following parameters:

- Pb concentration in plant tissues and Pb concentration retaining in soil (Rand and Around, 1997).
- Soil pH (Tan, 1996).
- Statistical analysis: the data was analyzed using SPSS for Windows XP (SPSS for Windows XP version 7.5.2.http://www.spss.com/spss/family. cfm)

RESULTS AND DISCUSSION

pH: The initial pH of the cultivated soil was 5.62. Except for the control, the pH of the soil increased when the cultivation period continued. The pH values ranged from 6.6 to 7.5 (day 45 to day 65); however, in a similar cultivation period the pH of cultivated soils were slightly different under all treatments (Table 1).

Table 1: Soil pH in the three specimen plants

	Soil $pH_{1:2\ in\ water}$			
Days	Control	*P. grandiflora*	*S. procumbens*	*A. philoxeroides*
0	5.61	5.62	5.62	5.62
45	5.71	6.60	6.78	6.66
55	5.95	6.38	6.38	6.67
65	5.98	6.98	7.58	7.41

Table 2: Lead concentration in plant tissue

	Lead concentration in plant tissue (mg/kg dried plant)		
Days	*P. grandiflora*	*S. procumbens*	*A. philoxeroides*
45	9.77 ± 0.13^{b}	12.33 ± 0.10^{a}	22.49 ± 0.17^{e}
55	8.12 ± 0.01^{c}	12.13 ± 0.05^{a}	15.44 ± 0.01^{f}
65	7.64 ± 0.03^{d}	9.77 ± 0.01^{b}	12.36 ± 0.02^{a}

Lead concentration in plant tissue: The three specimen plants *S. procumbens*, *P. granaiflora* and *A. philoxeroides*, were grown in lead contaminated soils (75 mg kg^{-1}). Lead concentration in soil and plant tissue was determined on day 45, 55 and 65 after planting. The amount of root biomass or root surface area is beneficial for heavy metal accumulation (Dushenkov and Kapulnik, 2000). This experiment found that *A. philoxeroides* exhibited excellent potential for lead accumulation, more than *P. granaiflora* and. *S. procumbens*. On day 45, *A. philoxeroides* showed significant differences in lead accumulation (22.49 mg kg^{-1}) when compared to those found in *P. granaiflora* (9.77 mg kg^{-1}) and. *S. procumbens* (12.33 mg kg^{-1}) (Table 2). This might be caused by A. *philoxeroides* forming dense roots with long stolons and large surface areas which are beneficial to accumulating lead in their tissues. *P. granaiflora* showed to be less effective in the phytoremediation system; this may be a result of their thickened taproot. Plant age generally affects the physiology of plant roots and roots of a young plant have a greater potential to absorb ions than those of an older plant (Marschner, 1995; Taiz and Eduardo, 1998). In this study, the ability of plants to uptake heavy metal was low when growth had continued for a longer period of time. Lead accumulation in all treatments decreased when plants became older (day 55 and 65). *A. philoxeroides* showed the highest percentage (29.99%) in lead uptake from the soil, more than *S. procumbens* (16.44%) and *P. granaiflora* (13.03%) (Table 3). Similar results were reported in rice (Anti *et al*., 2001), where it was found that N uptake rates slowed with increasing age. Tu *et al*. (2004) also observed that the arsenic-depletion rate by a 12-month-old fern was 42-52% of that observed for 3-month-old fern plants.

Lead concentration in soil: From the experiments it was found that all treatments exhibited significant differences in lead concentration in soil (mg kg^{-1} soil) at a confidence level of 95% when compared to the control. Lead concentration in soil under all treatments decreased between 30-80% (62.61-23.18 mg kg^{-1} soil) when compared to the control (75 mg kg^{-1} soil). The lowest lead concentration in soil was found in day 65 and lead concentrations retained in soils were 23.18, 31.09 and 42.48 mg kg^{-1} soil in treatments of *A. philoxeroides*, *S. procumbens* and *P. grandiflora*, respectively (Table 4). The results of lead concentration in soil confirmed those of the lead accumulation in plant tissue. A treatment of *A. philoxeroides* showed it to be the most effective lead extractor from soil (Table 1). The results from this experiment confirm those of Garcia *et al.* (2004) who noted that Pb and Zn concentrations in smilo grass (*Piptatherum miliaceum*) tissues were correlated with those found in the soil. It was found that *P. miliaceum* was the more effective than other grass species in removing lead from soil since more than 8 g of Pb can be accumulated in 1 kg plant (dry weight).

Table 3: Percentage of lead uptake by plants

	Percentage of lead uptake by plants		
Days	*P. grandiflora*	*S. procumbens*	*A. philoxeroides*
45	13.03%	16.44%	29.99%
55	10.82%	16.17%	20.59%
65	10.19%	13.02%	16.48%

Table 4: Lead concentration of soil in the three specimen plants

	Lead concentration in soil (mg kg^{-1} soil)			
Days	Control	*P. grandiflora*	*S. procumbens*	*A. philoxeroides*
45	76.05±0.15^{a}	62.61±0.42^{e}	47.15±0.16^{b}	45.89±0.18^{h}
55	75.08±0.14^{a}	51.82±0.34^{f}	39.61±0.17^{c}	30.59±0.52^{d}
65	75.01±0.13^{a}	42.48±0.56^{g}	31.09±0.15^{d}	23.18±0.22^{i}

CONCLUSIONS

The ability of three perennial plants, *S. procumbens*, *P. grandiflora* and *A. philoxeroides* to remove lead pollutants from contaminated soils was examined in this study. Lead analysis was conducted on the entire plant tissue. *A. philoxeroides* showed the highest lead content in its tissues, more than those observed in *S. procumbens* and *P. grandiflora*. This might be caused by *A. philoxeroides* forming long stolons, a massive fibrous roots system and large surface area which benefits the accumulation of lead. Since, *A. philoxeroides* has a high growth rate, is environmentally tolerant and is widely found in Thailand, it may be a practicable alternative for leaching lead from the contaminated soil in Thailand.

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