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Phytoremediation of Soils Contaminated by Organic Solvents using *Pinus taeda* and *Eucalyptus urograndis* Trees (Greenhouse Study)

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ABSTRACT: Phytoremediation is an emerging cost-effect remediation technology, and can be defined as the use of plants and associated microbes to reduce or degrade pollutants in the environment. Benzene and chlorobenzene contamination of soils is common in industrial sites throughout the world. We are exploring here the phytoremediation potential of tree plantations down-gradient from a mixed chlorobenzene/benzene plume at an industrial site in southern Brazil (Portão, RS), located in an old floodplain (terrace). The objectives of this study are to evaluate the survivorship of plants under pollutant exposure, and to assess the change in pollutant concentration when exposed to plants grown in the greenhouse. These results will be used to design a phytoremediation experiment at the field site. We conducted two greenhouse studies. First, we exposed *Pinus taeda* to a range of contaminant concentrations (similar to the field). No mortality was observed for any treatment. Second, we conducted a block-designed greenhouse experiment using Eucalyptus, Pinus, and a non-planted control (4 replications) placed on pots containing washed sand. A solution containing benzene and chlorobenzene were added to each pot. Leachate were collected daily from the bottom (through a valve), and nominal contaminant level was maintained. Aqueous solution was extract on organic phase (using hexane), and analyzed on GC/MS (Gas chromatography – mass spectrometry) equipment. Our preliminary results suggest that the presence of plants increase loss of these contaminants. We will next evaluate the use of Eucalyptus trees to remediate these pollutants at the field Site in Brazil.

Index terms: soil & water remediation, plant degradation, chlorobenzene & benzene contamination.

INTRODUCTION

Global annual expenditures to remediate contaminated soils and water are between $ 25-50 billion US dollars (Tsao, 2003). Benzene-based compounds (e.g., benzene, chlorobenzene, and 1,2-dichlorobenzene) are used widely as precursors for synthesis of pesticides and industrial chemicals and are common pollutants worldwide. Chlorobenzenes are a particularly pervasive problem leading to soil contamination due to inappropriate disposal practices and accidental leakage from storage tanks or pipes within production facilities. These compounds have low solubility and high lipophilic characteristics that promote their adsorption to soil organic matter and accumulation in the fatty tissue of organisms (Feidieker et al., 1995).

Phytoremediation is a remediation strategy defined as the use of plants and their associated microorganisms to achieve contaminate degradation, stabilization or attenuation (Arthur et al., 2005). This technology is an emerging, cost-effective alternative to the traditional remediation methods of soil excavation, washing/burning, and groundwater pump-and-treat approaches (Pilon-Smits, 2005).

Phytoremediation can be conceptualized into five categories (Pilon-Smits, 2005): (1) rhizodegradation, where plant roots and associated microbial flora degrade pollutants; (2) phytoaccumulation, where the plants accumulates the contaminants in their tissues; (3) phyto-volatilization, where plants facilitate the volatilization of the contaminants; (4) phytodegradation, where plant enzymes achieve pollutant degradation; and (5) phytostabilization, where plants reduce the contaminant bioavailability through absorption and precipitation in soils.

A site located in southern Brazil (Portão, State of Rio Grande do Sul – RS) is contaminated by several benzene-based compounds (benzene, chlorobenzene, and others). The site is a former pesticide manufacturing facility, placed in an old floodplain (terrace). The contamination was due to storage tank leaks, formulation processes, and disposal practices. Given the environmental and waste characteristics of the site, phytoremediation may be a feasible strategy to clean up the pollutants on this site. Therefore, the objectives of this study are: (a) evaluate the survival of plants under pollutant exposure; (b) evaluate phytoremediation of benzene-based compounds on controlled green-house conditions; (c) assess potential phyto-remediation of the pollutants at Portão Site (RS, Brazil).

MATERIAL AND METHODS

We propose to utilize tree plantings on Portão site (RS, Brazil) to help control movement of subsurface water to the creek (phytopumping) and,

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potentially, further reduce concentrations of benzene-based pollutants through phytoremediation. Before beginning this field experiment, we conducted two greenhouse experiments at The University of Georgia (Athens, GA, USA).

Plant Survival Experiment

To evaluate the survivorship of the trees across a wide range of contaminant concentrations, we conducted a short-term study in a lab hood with pine seedlings (*Pinus taeda*). A range of concentrations around the current groundwater concentration present in the field in Brazil (abbreviated as "CC") was used for this study. During 30 days, we exposed seedlings of *Pinus taeda* potted in small cones of PVC (20 cm high by 4.5 cm of diameter), containing an unfertilized commercial soil mix (Fafard 3M) and we irrigated them daily to field capacity using 5 contaminant treatments and 4 replications **(Table 1)**.

Greenhouse Phytoremediation Experiment

Two species widely planted in Southern Brazil (*Pinus taeda* and *Eucalyptus urograndis*) were used on a second experiment at greenhouse during four months (randomized block design), in order to quantify the phytodegradation of benzene-based compounds. The concentrations of the contaminants were based on the current concentration (CC) of contaminant in the groundwater found in Portão Site, RS **(Table 1)**. There were 2 treatments: 0xCC and 1xCC (4 replications each), for *Eucalyptus*, *Pinus* and No-Plant, all placed in pots filled with washed sand (to reduce potential contaminant sorption). To match groundwater conditions of the field, near constant water and contaminant levels were maintained in the soil columns/pots **(Figure 1)**.

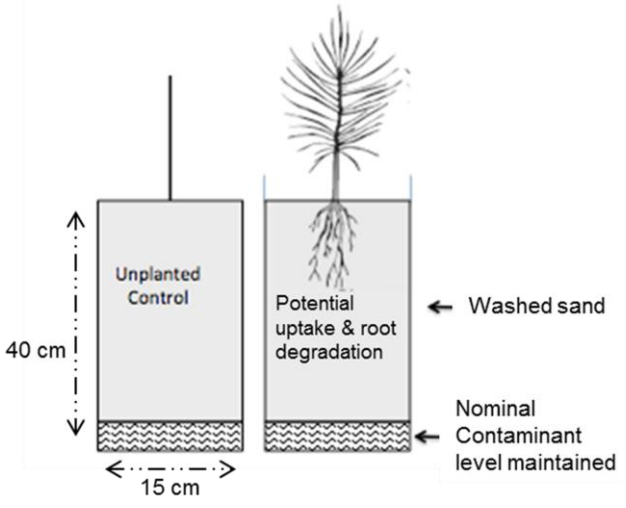

Figure 1 – Pots in the greenhouse with plant and unplanted control.

Plant growth was measured weekly by the height (H) from the soil surface to the apical bud, and the diameter (D) of the seedlings. Leachates from each pot were collected from the bottom of the pot (by a valve) and the organic contaminants were analyzed using GC/MS (Gas chromatography – mass spectrometry) following a liquid-liquid extraction using hexane to isolate the organic pollutant from aqueous phase.

RESULTS & DISCUSSION

For the preliminary dose-response experiment, after 30 days, no plant mortality was observed, even in the highest concentration treatment (100xCC), in which both chlorobenzene and benzene exceeded their aqueous solubility. In fact, plant growth was observed in all treatments (p=0.92) at rate of 2.0±0.8 cm/month **(Figure 2)**. These results suggest that trees can survive at levels of contamination greater than we expect in the field.

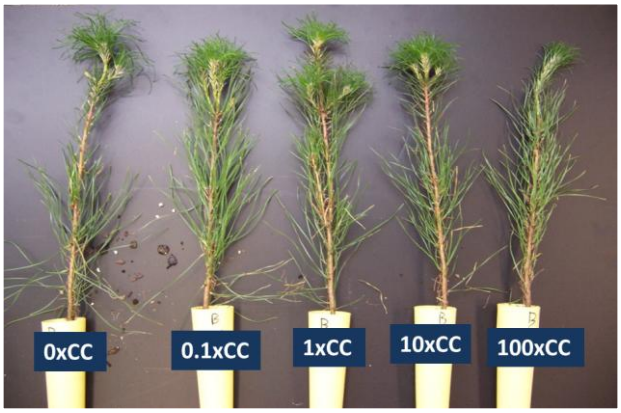

Figure 2 – Seedlings exposed to benzene-based compounds 30 days after exposure (no mortality). Seedlings not exposed to pollutants (far left) and highest concentration (far right).

For the second greenhouse experiment, our preliminary results suggest a sharp reduction of chlorobenzene on the presence of Eucalyptus for three consecutive applications of pollutant **(Figure 3)**. For the pot with no-plant, the reduction was not as fast, and the contaminant losses for this no-plant treatment likely reflect volatilization, sorption, and natural attenuation of the compound. However, the difference in concentration between the Eucalyptus and no-plant treatments is due to the presence of the trees suggesting an enhancement of compound degradation.

The trend results for benzene is similar to chlorobenzene, showing Eucalyptus enhancing degradation of the pollutant. We are proceeding to analyze the effect of Pinus trees to remediate these pollutants as well.

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Therefore, phytoremediation using Eucalyptus trees is a feasible technology that can be tested at the Portão Site (RS, Brazil). We are going to plant trees on the site, and use groundwater monitoring wells upgradient and downgradient to monitor pollutant concentrations, as well as potential phytopumping effect due to the presence of trees on the site. Plant tissues will be sampled to monitor any accumulation of the pollutants in the trees. The area select for this field experiment is at the edge of the pollutant plume on Portão Site (Portão, RS, Brazil).

CONCLUSIONS

Our greenhouse experiments suggest Eucalyptus trees can phytoremediate soil and water contaminated by benzene and chlorobenzene. We are proceeding to test the potential for Eucalyptus trees to phytoremediate soil and groundwater in the field Site in Brazil.

ACKNOWLEDGMENTS

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Table 1 – Treatment solution concentration and solubility of pollutants used in preliminary tree-survival study.

Compound	Concentrations in mg L^{-1} of 3 contaminants (CC*)					Solubility in water (at 20°C), in mg L^{-1}
	Control (0)	*0.1xCC*	*1xCC*	*10xCC*	*100xCC*	
Chlorobenzene	0	10	100	1,000	10,000	500
Benzene	0	5	50	500	5,000	1,800
1.2-Dichlorobenzene	0	0.03	0.3	3	30	8,700

*CC = Current Concentration in the Field Experiment in Brazil

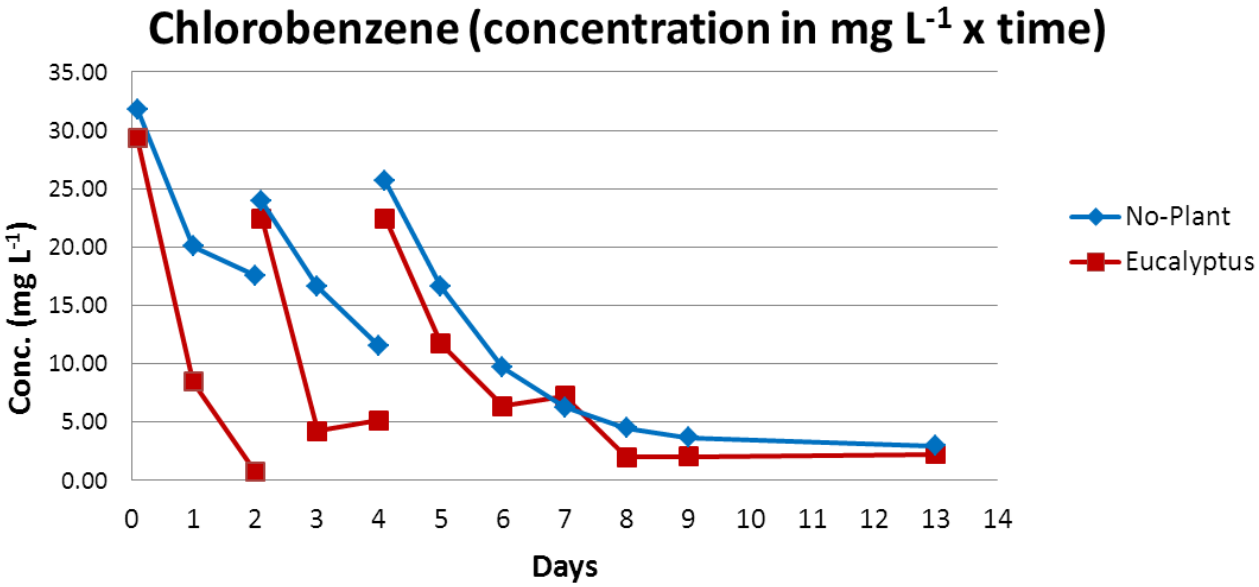

Figure 3 – Preliminary results of the influence of Eucalyptus and a no-plant control on three applications of chlorobenzene in our greenhouse experiment.