Phytoremediation of polychlorinated biphenyl (PCB) contaminated soils: an alternative for pesticides contaminated soils?

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Abstract

The use of plants for soil organic contaminant remediation (phytoremediation) offers a lower cost advantage over currently available engineering methods. The objective of this study was to determine the effectiveness of alfalfa (*Medicago sativa* L.), flatpea (*Lathyrus sylvestris* L.), sericea lespedeza (*Lespedeza cuneata* (Dum.-Cours.), deertongue (*Panicum clandestinum* L.), reed canarygrass (*Phalaris arundinacea* L.), switchgrass (*Panicum variegatum* L.), and tall fescue (*Festuca arundinacea* Schreb.) for phytoremediation of polychlorinated biphenyl (PCB) contaminated soils. The crop species screening study indicated that all plant species treatments had a significantly higher level of PCB transformation compared to the unplanted control treatment. Statistically significant differences in PCB transformation were also observed among the crop species in the study. To the best knowledge of the authors, this study was the first of its kind to show that plants in general, and forage crops in particular, are very effective for phytoremediation of PCB contaminated soils. Since some of the most commonly found pesticides are organochlorine compounds like PCBs, phytoremediation could be a less costly and an environmentally friendly alternative for many of the world's pesticide contaminated soils.

Introduction

Contamination of soils and waters with polychlorinated biphenyls (PCBs) is often associated with the manufacturing, handling, use, and disposal of these chemicals. Despite the fact that industrial use of PCBs has been severely reduced, their extreme persistence in the environment and ability to bioconcentrate in the food chain mean human health concerns are still warranted. PCBs are present in small quantities in the air and water through out the globe and the soil and sediments are major sinks sequestering the greatest amount of PCBs in the terrestrial environment. The latter pools represent environmental and human health risks that need remedial action (Cousins *et al*., 1998; Hickey, 1999).

Currently available engineering-based remedial technologies for PCB contaminated soils are disruptive and expensive. Bioremediation technologies are scientifically sound, environment friendly and less expensive alternatives. Phytoremediation is one such highly appealing technology (Schnoor *et al*.1995; Wenzel *et al*., 1999). Phytoremediation is an *In Situ* bioremediation strategy that has been gaining increasing recognition. The cultivation of plants as a remedy for contamination that occurred through incidental or accidental introduction of wastes in the environment is an appealing choice. Phytoremediation employs a natural system or an enhanced variation thereof, to eliminate the need for removing contaminated soil to locations where remediation cannot be assured. The phytoremediation concept is based on the well-known fact that plants in association with the rhizosphere microflora are capable of degrading soil xenobiotics.

Past plant-PCB interaction experiments were done mainly for the purpose of looking into the food chain effect (Webber *et al*., 1990; Gan and Berthouex, 1994). This is particularly understandable since PCBs are a group of organic contaminants capable of bioconcentrating in tissues. Webber *et al*. (1990) looked into the possibility of PCB uptake by corn (*Zea mays* L.), cabbage (*Brassica oleracea var. capitata* L.) and carrot (*Daucus carota* L.) from contaminated sewage sludge. Their findings revealed that carrots had the highest PCB concentration in the plant tissues followed by cabbage and corn. However, these concentrations, with the exception of carrots, were very small and not related to the soil PCB contamination levels. Moreover, the highest accumulation of PCBs was observed in the carrot peels. Other reports have also confirmed that the risk of PCB translocation into the corn grain or corn stover to be negligible (Gan and Berthouex, 1994).

Phytoremediation studies on PCBs are very limited and the reported cases refer mainly to tissue culture or soil microcosm studies (Mackova *et al*., 1997; Epuri and Sorensen, 1997). In a study using hairy root cultures of *Solanum nigrum* L, Mackova *et al*. (1997) reported a 40% mineralisation of the 100-mg/kg commercial PCB mixture Delor 103 after 30 days of incubation. Epuri and Sorensen (1997) reported an enhanced mineralisation of Aroclor 1260 in a soil microcosm planted for 180 days with tall fescue (*Festuca arundinacea* Schreb.) compared to that in an unplanted control.

Available literature is very sketchy and phytoremediation of PCB contaminated soils is a largely untouched area of research. This study was conducted to determine if some forage and conservation crops could be used for phytoremediation of PCB contaminated soils.

Materials and methods

Three legumes and four grass species were screened in this study. The legumes were alfalfa (*Medicago sativa* L.), flatpea (Wagner pea), (*Lathyrus sylvestris* L.) and sericea lespedeza (*Lespedeza cuneata* Dum. -Cours.). Grass species were deertongue (*Panicum clandestinum* L.), reed canarygrass (*Phalaris arundinacea* L.), switchgrass (*Panicum virgatum* L.), and tall fescue (*Festuca arundinacea* Schreb.). The experiments were conducted at the Department of Natural Resource Sciences (University of Maryland) growth chamber facility.

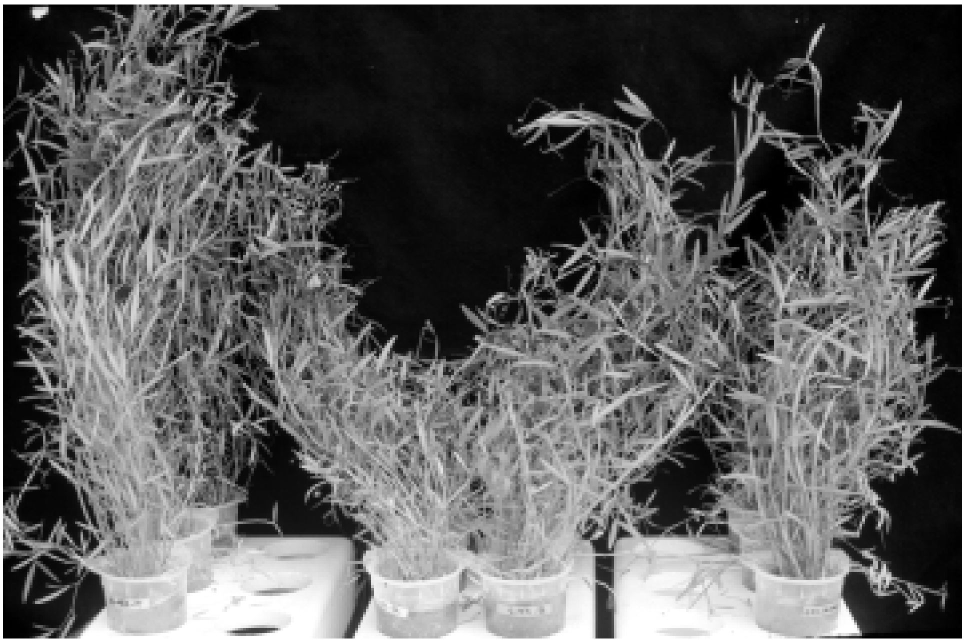

Figure 1. Legume species grown on PCB contaminated soil (third row from left to right)

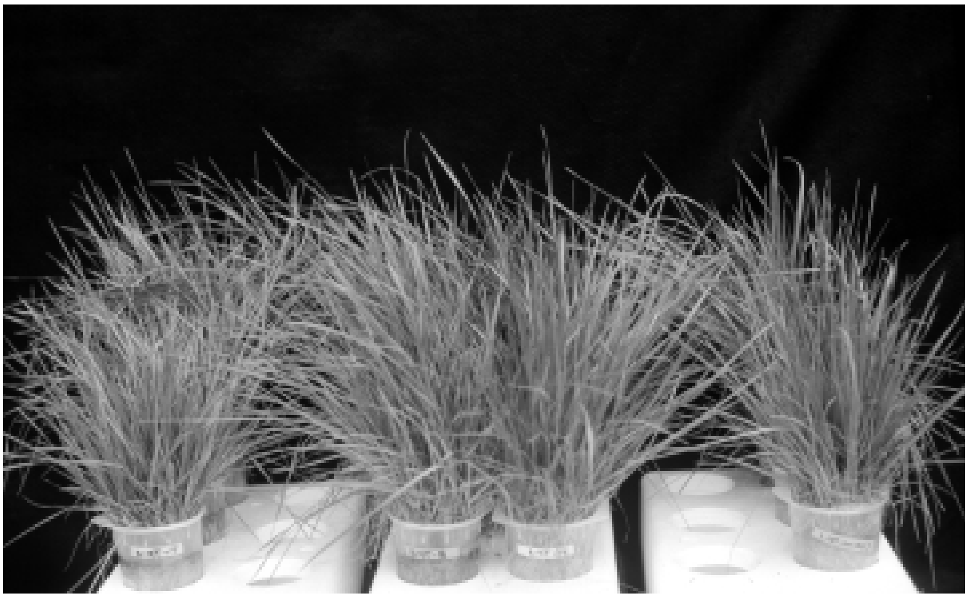

Figure 2. Grass species grown on PCB contaminated soil (second row from left to right)

Both the analytical standard and pure chemical Aroclor 1248 were obtained from ChemService, West Chester, PA. The targeted contaminant concentration of 100 mg/kg of soil and 25 kg of soil / contaminant was used for this experiment. The experimental design for the crop species screening study was Split-plot in a Randomised Complete Block Design (RCBD). The chemical treatments in each box were used as main plots where as the crop species were the sub-plot treatments. Data was analysed using Proc MIXED and multiple mean comparisons were done with Tukey-Kramer test (SAS Systems Release 7, 1999 Cary, NC).

At the end of each experiment, composite soil samples were placed in Quorpak glass containers and stored in the freezer (-50^{0}C) until extraction. Soil PCB extractions and analysis were done using methods described by Lopes-Avila *et al.* (1995). Quality assurance-quality control checks were conducted with each analysis. These included use of standards with known concentrations, material blank measurements, repeat analysis, and fresh spike recoveries.

Results and Discussion

At the end of the 4-month growth chambers crop species-screening experiments, less than 33% of Aroclor 1248 was recovered from all planted pots (Table 1). In contrast, more than 80% of the initial soil Aroclor 1248 levels were recovered from the control unplanted treatment.

Table 1. Residual Aroclor 1248 levels (mg/kg) in soil after 4 months of plant growth in PCB amended soil.

Treatment		PCB (mg/kg)
Legumes	Alfalfa	23a*
	Flatpea	28ab
	Sericea lespedeza	29ab
Grasses	Deertongue	28ab
	Reed canarygrass	27a
	Switchgrass	31ab
	Tall fescue	33b
	Control (no crop)	82c

*Means followed by the same letter are not significantly different as determined by Tukey-Kramer multiple comparison procedure (P<0.05)

This study is in complete agreement with the findings of Epuri and Sorensen (1997) regarding the use of tall fescue in PCB phytoremediation. However, due to the more comprehensive nature of this study, tall fescue, although better than the unplanted controls, did not perform as well compared to other species. As a result, this species was not considered for further detailed evaluation. Based on the results from the screening studies, two grass species were further evaluated for their phytoremediation abilities under sterilised and unsterilised soil conditions. The results from the rhizosphere characterisation study indicated that planting increased the biological activity (microbial counts and rhizosphere dehydrogenase activities) in the soil and this increased biological activity was responsible for the significantly higher levels of PCB transformation in the planted pots compared to unplanted controls (data not presented).

In this regard, it should be mentioned that there are two distinct mechanisms of PCB biodegradation, aerobic and anaerobic dechlorination. The aerobic dechlorination is a stepwise oxidative degradation of the biphenyl molecule via a series of intermediate products. In contrast, anaerobic dechlorination takes place with the replacement of Cl atoms by H atoms in the absence of O_2.

Since the less chlorinated PCBs are simple, more water soluble and available, they are more amenable to aerobic biodegradation than the more chlorinated congeners (Bedard, 1990; Higson, 1992; Hickey, 1999). The principal dechlorination mechanism for highly chlorinated PCBs is anaerobic reductive dechlorination that requires a cometabolic substrate and usually takes place at the *meta* and *para* positions. This preferential dechlorination during anaerobic biodegradation invariably results in an increased percentage of the PCBs with *ortho* chlorines (Higson, 1992). On the other hand, anaerobic reductive dechlorination of the more chlorinated PCBs results in the accumulation of mono-trichlorobiphenyls, which are easily degraded by aerobic microorganisms (Bedard, 1990).

We assume that plants affect the fate of PCBs in soil by providing the necessary environment for their biodegradation (greater number of microorganisms, exudation of co-metabolic substrates, enzymes and providing relatively anoxic pockets). Overall, plants appear to be enhancing the biodegradation of chlorinated hydrocarbons in soil and this potential could be utilised to remediate the widespread problem of soil organochlorine pesticide contamination.

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