# The Impact of Phytoremediation on the Toxicity of Soil Contaminants

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**Abstract**

A field project located at the US Naval Port Hueneme, California, was designed to evaluate changes in contaminant concentrations and toxicity during phytoremediation. Vegetated plots were established in petroleum (diesel and heavy oil) contaminated soil, and field assessment occurred over a two-year period. Plant species were chosen based on initial germination studies and included native California grasses. Toxicity of soil in vegetated and unvegetated plots was evaluated using Microtox®, earthworm, and seed germination assays. The reduction of toxicity was affected more by contaminant aging than by the establishment of plants. However, total petroleum hydrocarbon concentrations were lower by the end of the study in the vegetated plots when compared to the unvegetated soil. Although phytoremediation is an effective approach for clean-up of petroleum contaminated soil, a long management period will be required for significant reduction in contaminant concentrations.

## Introduction

Petroleum products are common soil contaminants and often contain potentially toxic compounds, particularly the polycyclic aromatic hydrocarbons (PAHs). Although soil concentrations of petroleum contaminants are highly regulated, these organic compounds may not pose an environmental threat if they are biologically unavailable (Alexander, 1995). Unfortunately, bioavailability is difficult to define unambiguously and equally hard to quantify.

Bioremediation is a common approach to clean-up soils contaminated with petroleum products and use microorganisms to decompose soil pollutants. A variation of bioremediation is phytoremediation, the use of higher plants to further enhance removal of soil contaminants. Although less costly than other remediation alternatives, bioremediation and phytoremediation often do not result in complete removal of contaminants, and the fate of the degradation products is unknown. Bioremediated soils may be deemed as having reached an acceptable end-point if the contaminants can be shown to be biologically unavailable.

Several published studies have evaluated the effect of plants and the associated rhizosphere on the fate of petroleum contaminants (Reilley et al., 1996; Ferro et al., 1994; Schwab and Banks, 1995; Aprill and Sims, 1990). For the most part, the presence of plants enhanced the dissipation of the contaminants. Also, in the studies using $^{14}C$-labeled contaminants in closed plant chambers, mineralization is greater in rhizosphere soils than in unvegetated soil, indicating that the bioavailability of the contaminant is increased in the rhizosphere (Ferro et al., 1994; Anderson and Walton, 1995; Banks et al., 1999). The associated reduction in contaminant toxicity in soil due to phytoremediation has never been quantified.

**Experimental Protocol**

A field assessment was conducted using contaminated soil at the Department of Defense National Test Facility in Port Hueneme, CA. Soil in the study area was contaminated with diesel fuel and heavier oil contaminants. A contained treatment cell was designed and constructed on-site, and petroleum contaminated soil transferred to the cell to a depth of approximately 75 cm. The entire study area was approximately 20 m x 35 m and was divided into 12 rectangular plots in a randomized block design with three treatments (two plant mixtures and an unplanted control) and four replicate blocks. Different vegetation regimes selected for the local area were evaluated for their remediation potential by germination studies. Based on germination results, vegetated plots contained one of two plant species mixtures. Unvegetated plots were used as controls. The toxicity of the soils was evaluated using the Microtox® Solid-Phase Test procedure, earthworm toxicity, and germination tests. Total petroleum hydrocarbons were analyzed by gas chromatography. Extensive microbial testing was also performed.

**Results**

Various toxicity assessments were performed throughout the two-year study. Germination and emergence of lettuce (*Latuca sativa*) indicate that the initial toxicity was overcome in all treatments six to nine months after the initiation of the project. The Microtox® results show that the $EC_{50}$ values slightly decreased for 11 months from the beginning of the study, followed by a significant increase toward the end of the experiment. These two phases are indicative of a slight increase in toxicity (0-11 months), and a subsequent reduction (11-29 months). However, all these values are significantly smaller than 2%, which is the hypothetical demarcation between toxic, and non-toxic soil. This would suggest that more time would be necessary for the effect of the plants to be considerable. In fact, although some of the changes were significant ($p \leq 0.01$), there was no overall impact of vegetation on soil toxicity as indicated by the $EC_{50}$ values. The earthworm toxicity was not evaluated until eleven months into the study. The soils were found to be non-lethal to the worms; therefore, we focused on changes in mass of the worms after the incubation period. The average mass gain by the worms was greater in the vegetated soils at all sampling dates with near zero mass gain in the unvegetated soils at 11 and 14 months. However, the difference is significant only at 14 months. By the end of the field trial, the differences between means were quite small. The presence of plants certainly accelerated the process of improving the suitability of the soils to worm growth, but the passage of time appeared to be an equally important factor for reduction of toxicity as the presence of plants.

One of the key parameters being assessed during the field project was total petroleum hydrocarbons (TPH). Preliminary analyses showed that of the total extractable material from a soxhlet extraction, only 10% were non-polar compounds (i.e., petroleum hydrocarbons). The remaining 90% of the compounds were polar materials, typical of a highly weathered material, and are extremely difficult to degrade. These preliminary data suggest that the contaminant had undergone extensive transformation, including some humification, prior to the initiation of this experiment.

During the first year of the experiment, dissipation of the TPH followed the same trends in all vegetative treatments. This is typical for field studies of phytoremediation of soil contaminated with petroleum products (Nedunuri et al., 2000; Banks et al., 2000). Initial degradation of the hydrocarbons occurs simply as a result of the soil disturbance incurred as the soil is placed in the remediation cell (Hutchinson et al., 2001). All of the soil was thoroughly aerated during the process, and new surfaces were exposed to microbial activity. By fourteen months, however, the trends for the remainder of the experiment were beginning to emerge. Average TPH concentrations changed very little during the last 15 months in the unvegetated controls, whereas the concentrations continued to decline in the vegetated plots. All differences between unvegetated and vegetated plots were significant ($P<0.01$) for the last 15 months of the experiment.

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