Using Plants to Remediate Petroleum-Contaminated Soil

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Title: Using Plants to Remediate Petroleum-Contaminated Soil
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Objective(s) of the Research Project:

1. To conduct greenhouse studies to screen plants for their ability to germinate and grow in weathered crude oil-contaminated soil with or without amendments.
2. To survey and collect plant species currently growing on contaminated sites and screen the plants and rhizosphere microorganisms for their ability to enhance biodegradation of petroleum contaminants.
3. To conduct an on-site field study to evaluate likely combinations of plants and management systems to enhance phytoremediation of weathered crude oil -contaminated sites.
4. To develop a model that can be used to summarize and aid in the interpretation of experimental data collected in both the laboratory and field during the first experimental season.

Progress Summary/ Accomplishments:

Field Study

The field site in El Dorado, AR is located in a bermed area that is the site of an intentional spill by vandals approximately three years ago. The experimental plots consist of four replicates of the following treatments: (1) nonvegetated-nonfertilized control, (2) fescue-ryegrass-alfalfa + fertilizer, and (3) fescue-bermudagrass + fertilizer. Each field plot has 12 microplots (‘soil socks’) that contain homogenized soil that allow monitoring of the field treatments, on a smaller scale, with less effect of field variability of the contaminant levels.

Biological and chemical analyses of the time = 0 composite soil samples are presented in Tables 1 and 2. The bacterial, fungal, and petroleum degrader numbers were typical for levels of biological populations in crude oil-contaminated soil. Plant available nutrient levels were not adequate for optimum plant growth and necessitated application of fertilizer and lime at rates of 780 and 1,450 kg/ha, respectively, for the fertilized treatments. Fescue and ryegrass, cool season grasses, and the legume, alfalfa, were seeded on 15 October 1999 and bermudagrass, a warm season grass, was sprigged on 17 May 2000 and 807 kg/ha of 13-13-13 fertilizer was applied to the appropriate plots. All plant species appear to be exhibiting adequate plant growth at this time.

The Total Petroleum Hydrocarbon, biomarkers, and Polycyclic Aromatic Hydrocarbon analyses in the initial soil samples have been completed and data are currently being evaluated. The next soil sampling will occur in July 2000.

Table 1. Bacterial, fungal, and petroleum degrader numbers in the crude oil-contaminated soil sampled 6 January 1999 at the initiation of the field study in El Dorado, AR.

Bacteria	Fungi	Petroleum Degraders
$\log_{10}$ Colony Forming Units/g dry soil		$\log_{10}$ Most Probable Number/g dry soil
6.5754 ± 0.1518*	4.5464 ± 0.1489	3.7813 ± 0.5441

*Values are the geometric mean of seven samples +/- one standard deviation.

Table 2. Chemical properties of the crude oil contaminated soil samples collected 6 January 1999 at the initiation of the field study in El Dorado, AR.

Mehlich 3 Extractable					pH	Total	
P	K	Ca	Mg	Na		C	N
mg/kg					(1:1)	-----%----	
5*	44	351	44	111	5.5	4.65	0.055

*Values are the mean of four samples.

Greenhouse Study

Survival and growth of alfalfa, ryegrass, fescue, bermudagrass, and crabgrass in unamended or soil amended with inorganic fertilizer, broiler litter, hardwood sawdust + inorganic fertilizer, and papermill sludge have been completed recently. Parameters measured included plant shoot and root biomass and soil chemical parameters. Statistical analysis of the data is underway.

Mathematical Model

Our initial model of phytoremediation consisted of two soil zones, the rhizosphere and the bulk soil. The current version of the model incorporates a root zone, six rhizosphere zones (concentric with the root structure and with individual degradation rate constants), and a bulk soil zone. The model is driven by a forcing function that describes root growth and senescence (at present a simple, annual sinusoidal variation with a 20 day lag between onset of growth and senescence). A typical model run for conditions where the root turnover is 0.6% per day and the root volume is 5% of the total volume is shown in Figure 1. The parameters relating the rhizosphere volumes to the root volume were derived from simulations with virtual roots that have been presented in previous quarterly summaries. The rhizosphere thickness modeled here encompasses a total thickness of 1.8 millimeters radially outward from the root surface; each of the six layers is 0.3 mm in thickness.

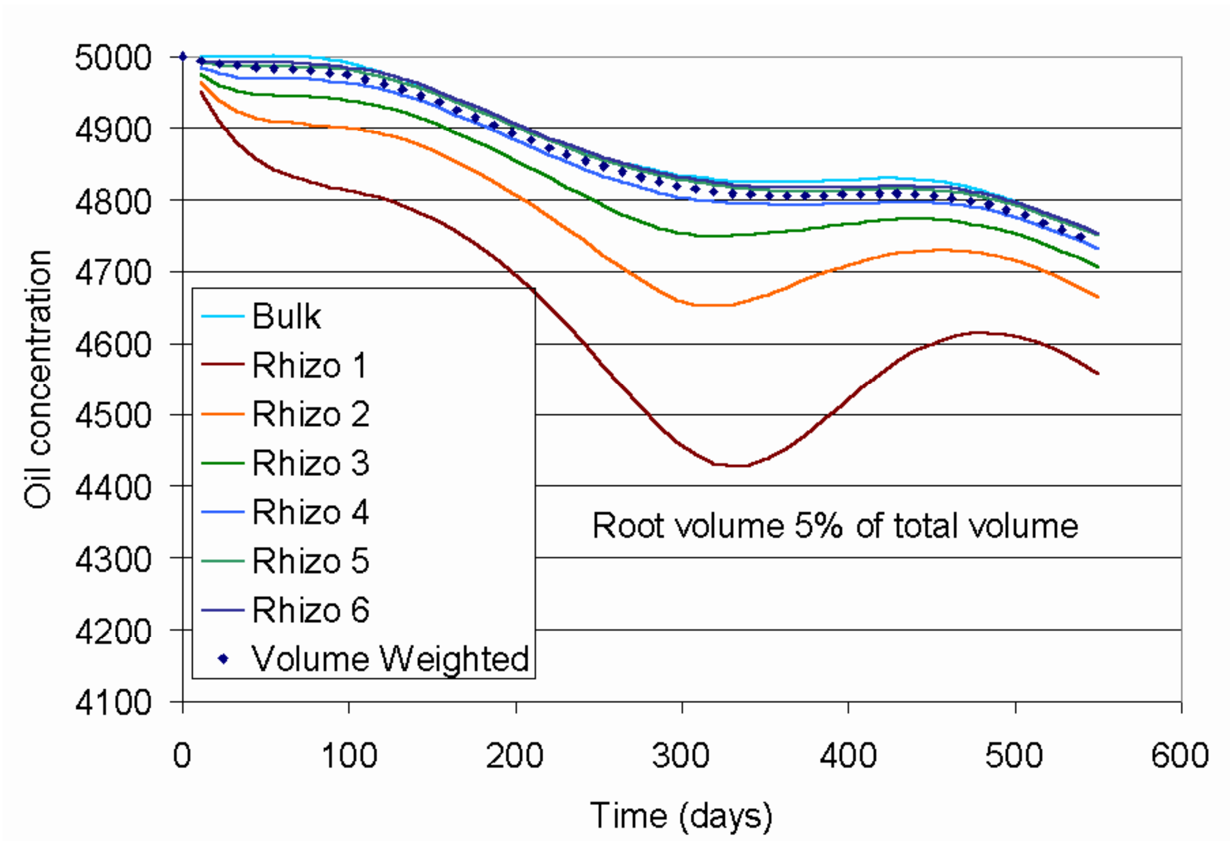

Figure 1. Multi-rhizosphere model predictions for decrease in oil concentration

The degradation rate constant in the innermost 0.3 mm rhizosphere layer was taken to be 10 times larger than that in the bulk soil – the first order rate constant was adjusted downward with each successive layer such that the final layer was approximately 1.5 times the bulk soil value. Thus, the Rhizo1 curve shows the greatest depletion of the oil in this simulation. An interesting feature of this simulation is the increase in the concentration in the rhizosphere layer following 325 days. This behavior follows from the root growth and senescence forcing functions in which the active growing season begins at about 325 days, and the penetration of the roots into regions where the oil concentration is higher, which results in an "influx" of more contaminated material into the rhizosphere zone. Because the model is a well-mixed box model, this movement of contaminated material into the root zone should manifest as an increase in the overall concentration of this zone. This simple approach can nonetheless provide valuable insight into the management of contaminated sites. In particular, initial sensitivity studies on the rhizosphere volume and root turnover rate suggest that the establishment of a stable root mass is more important than inducing rapid growth and senescence of the root system. A simulation in which the magnitude of both the growth rate and senescence rate was doubled (with an 18 day lag between them), and no effect was observed in the end-of-simulation bulk soil concentration. It is clear that additional information regarding the effect of roots on the degradation rate of oil in the field is needed before this model can used to reliably predict the effect of phytoremediation.

Publications/ Presentations:

Bowen, M.L. 1999 A mathematical model of phytoremediation of hydrocarbon impacted soils including an L-system approach to rhizosphere volume estimation, Masters Thesis Univ. Arkansas, Fayetteville

Bowen, M., G. Thoma, D.C. Wolf, and C.A. Beyrouty. 1998. A mathematical model of phytoremediation for hydrocarbon-impacted soils. *In* K.L. Sublette (ed.) Proc. 5th International Petroleum Environmental Conf., Albuquerque, NM, 20-23 Oct. 1998. Integrated Petroleum Environmental Consortium, Tulsa, OK.

Thoma, G.J., M.L. Bowen, C.A. Beyrouty, and D.C. Wolf. 1999. An L-systems approach to rhizosphere volume estimation. p. 125. *In* K.L. Sublette, G.J. Thoma, and T.J. Ward (ed.) Proc. 6th International Petroleum Environmental Conf., Houston, TX. 16-18 Nov. 1999. Integrated Petroleum Environmental Consortium, Tulsa, OK.

White, Jr., P.M., L.J. Krutz, W.D. Kirkpatrick, D.C. Wolf, C.M. Reynolds, and G.J. Thoma. 1999. Phytoremediation of petroleum-contaminated soils. p. 392-406. *In* K.L. Sublette, G.J. Thoma, and T.J. Ward (ed.) 6th International Petroleum Environmental Conf., Houston, TX. 16-18 Nov. 1999. Integrated Petroleum Environmental Consortium, Tulsa, OK.

Future activities:

Continue development of the mathematical model, looking at making the root structure be time variable so rhizosphere development through time can be assessed. Continue sampling field location for TPH, microbial populations, and plant available nutrients. Complete statistical analysis of greenhouse data.

Supplemental Keywords: Arkansas (AR), petroleum, phytoremediation, EPA Region 6, rhizosphere