Development and Field Tests of a Multi-Process Phytoremediation System for Decontamination of Soils

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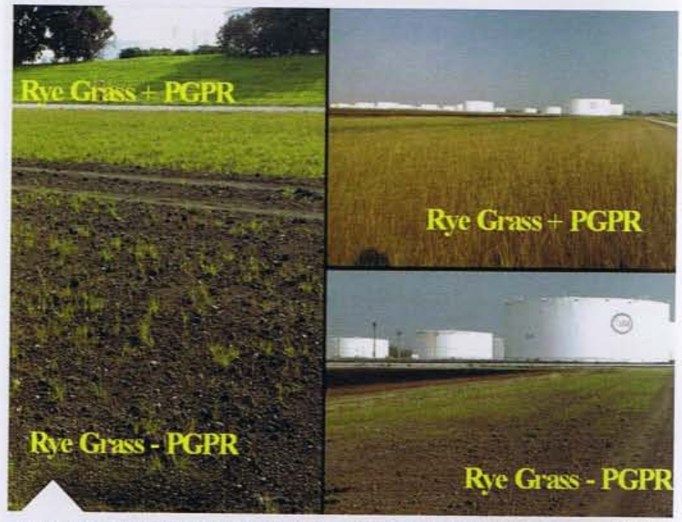
Effective remediation processes for persistent organic pollutants (POPs), metals and salt are a significant need in today's industrialized environment. Examples of organic contaminants of concern are polycyclic aromatic hydrocarbons (PAHs), total petroleum hydrocarbons (TPHs) and chlorinated hydrocarbons. Metals of concern include copper, cadmium, nickel, lead, zinc and arsenic. Salt contamination of soils is a major problem for the upstream oil and gas sector. The levels of these contaminants are increasing in the environment due to anthropogenic release. Their toxicity, mutagenicity and carcinogenicity pose significant problems in soils, particularly whenever a change in land usage is envisioned. We have developed an effective multi-process phytoremediation system (MPPS) (plant-based bioremediation). The system is applicable to any soil system where plant growth is feasible. An added benefit of the MPPS we have developed is significantly increased general plant stress tolerance. This includes tolerance to heat, drought, moisture and salt, which broadens the range of sites available for remediation and land reclamation.

A number of techniques have been investigated for remediation of POPs, metals and salt from soils. However, they are either ineffective, too slow, too costly or too cumbersome. For instance, assuming a 10-acre lead contaminated site, off-site solidification/stabilization would cost ~\$12 million, soil washing would cost ~\$6 million, an asphalt cap or a soil cap would cost ~\$1 million. In situ microbial bioremediation has been attempted; however, low biomass usually limits the efficacy of such systems, and it is not useful for metals. Conversely, phytoremediation holds great promise and has received recent attention for remediation of POPs and metals in soils.

Phytoremediation has the following advantages: There is no size restriction for remediation sites; it is suitable for all geographical locations that can support plant growth; it is "green" and solar driven; it is low in cost, relative to conventional methods of remediation. Unfortunately, when high levels of contaminants are present in soils, many plants can not attain sufficient biomass for acceptable rates of remediation. This is due, in part, to oxidative stress induced by the chemicals, and because contaminated soils are often nutrient poor and lacking in beneficial soil microbes. Our multi-process phytoremediation system has overcome these problems.

To improve the remediation process, multiple complimentary techniques that target different aspects of POPs, metal and salt removal have been combined. The result is an enhanced multi-process phytoremediation system with accelerated remediation kinetics that results in more rapid and more complete removal of POPs and metals from soil. Notably, in addition to removing POPs from soil, our findings suggest that the MPPS also metabolizes the POPs to non-toxic molecules. The MPPS can also be used to bioaccumulate salt and metals in plants, which can subsequently be removed from the soil.

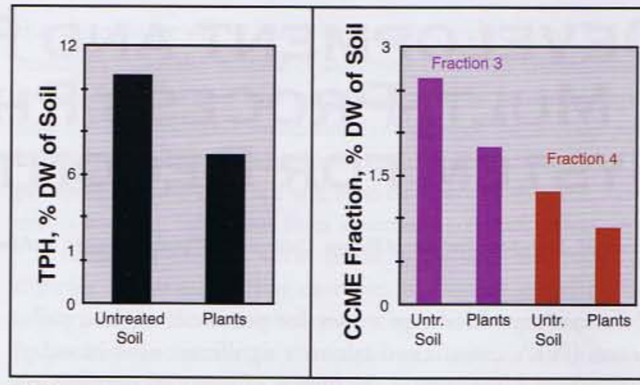


FIELD TEST AT IMPERIAL OIL LAND FARM IN SARNIA, ON AFTER 120 DAYS.

BARLEY/RYE ± PGPR AT THE IMPERIAL OIL LAND FARM IN SARNIA, ON, 30 – 40 DAYS AFTER PLANTING (SUMMER 2005).

The MPPS combines: 1) land farming for aeration, physical volatilization, and photochemical degradation, 2) microbial remediation using bacteria that start the degradation of organic contaminants, 3) phytoremediation (plant growth) with plant growth promoting rhizobacteria (PGPR). *Pseudomonas putida*, the PGPR used in our current system, also functions as a contaminant-degrading bacteria.

The MPPS works because the complementary processes target different facets of the remediation process, both temporally and in terms of the different contaminants that are targeted by each technique. Thus, remediation is rapidly initiated and is sustained throughout the growth season. In particular, the PGPR prevent production of stress ethylene and they synthesize auxin (a plant hormone that regulates growth). This promotes



TPH REMOVAL FROM IMPERIAL OIL LAND FARM IN SARNIA, ON. RYE/FESCUE, 120 DAYS (2005, YEAR 2 OF REMEDIATION).

vigorous root growth under stress conditions. With PGPR, the large amount of root biomass in the soil allows for effective partitioning of contaminants out of the soil. Numerous processes, both physical (eg. adsorption) and biological (eg. interactions involving root exudates and microbes) occur in the rhizosphere, and lead to high rates of metabolism of POPs, and sequestering of salt and metals.

Over the past 7 years, we have extensively tested the MPPS in a variety of soils in the greenhouse, and in field sites in Ontario and Alberta. A brief summary of our results to date are presented below:

Greenhouse experiments

1. 90 % of creosote in spiked soil at 2 g/kg was removed in a single 4-month growth season. This included high molecular weight recalcitrant PAHs.
2. Approximately 50 % of PAHs were removed in 4 months from an industrial brownfield soil from Dundas, Ontario, contaminated since World War II with PAHs (500 ppm, ≥ 4 rings).
3. More than 90 % of TPHs (50 g/kg) were removed from weathered contaminated soils acquired from Imperial Oil. This was accomplished in two 4-month growth seasons and included the major toxic fractions of petroleum (C15-50, CCME fractions 3 and 4).
4. Metals (Cu, Pb and Cd) were removed from spiked soils. They were isolated to the root tissue.
5. Use of PGPR resulted in a 100 % increase in plant performance in salt contaminated soil from an oil well site in Alberta.

Field studies

1. We completed field tests at Imperial Oil in Sarnia, Ontario in 2004 and 2005. The soil was highly contaminated with oil sludge (100 to 150 g/kg). The field test worked exceptionally well. Remediation rates were on par with greenhouse trials (40 to 50 % TPH remediation in 4 months, including CCME fractions 3 and 4). We now have evidence that the oil is degraded in the soil.

Plants + PGPR at a biopile (1 % TPH) in Turner Valley, AB. Rye/fescue growth after 60 days (summer 2005, year 1 of remediation).

2. Field tests in 2005 at two oil contaminated sites in Alberta were successful. At each site, 1 % TPH (mostly CCME fractions 3 and 4) were remediated by 35 %.

3. Field tests for removal of DDT were performed in Summer/Fall 2005. Rye and millet were grown for 90 days in the field, which had a low level of DDT in the soil (~0.8 µg/g). Approximately 35 % DDT remediation was achieved using the MPPS.

Based on our results, we can confidently predict that sites heavily contaminated with organic chemicals can be remediated in 2 to 5 years. Our evidence also suggests that salt and metals can be remediated using the MPPS. The cost of such a clean up would be a fraction of the cost of other remediation practices. Following our successful greenhouse and field experiments we are planning to expand the applications of the MPPS to remediate other contaminants, and other sites such as urban brownfields. ■

Further Reading:

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