Field-scale assessment of phytoremediation at a former oil tank battery in Bruderheim, Alberta

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Abstract
A 3-yr study to assess the effectiveness of plant-based systems to reduce contaminant levels to environmentally acceptable endpoints (as defined by the Canadian Council of Ministers of the Environment; CCME) was established at a former tank battery near Bruderheim, Alberta. Four treatments (unplanted, unfertilized control; unplanted, fertilized control; a standard cool-season grass/legume mixture; and a locally optimized grass/legume mixture) were compared in a randomized complete block design (n=4). The site was monitored for three years, with soils sampled (0–15 cm and 15-45 cm) at the end of each growing season. Analyses included total petroleum hydrocarbons (TPH), polycyclic aromatic hydrocarbons (PAHs), and CCME PHC-fractions. Plant assessments (species composition, above- and below-ground biomass) also were conducted at the end of each growing season. After three growing seasons, TPH concentrations averaged across the site had been reduced by 62% in the surface and 64% subsurface soils. Reductions in PHC concentrations were generally greater in the plots amended with fertilizer and compost, but were similar in the planted and unplanted plots. Reductions in the F2 (C6-C10) fraction, however, generally occurred more rapidly in the planted treatments. There were no significant differences between the standard and locally optimized plant mixes.

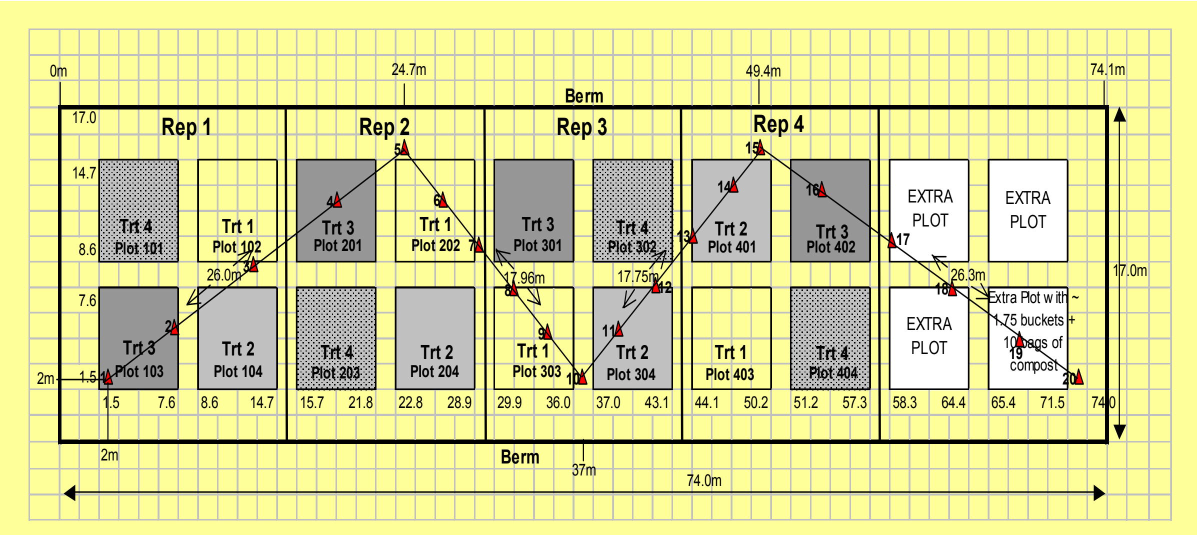
Key Words
Phytotechnology, plant–assisted bioremediation, enhanced rhizodegradation, petroleum hydrocarbons.

Introduction
Phytotechnologies involve the plant–assisted bioremediation of organic and inorganic contaminants and are essentially a form of ecological engineering that depends on natural, synergistic relationships among plants, microorganisms and the environment. Since 1998, our research has focused on assessing the effectiveness of phytotechnologies as a means of reducing petroleum hydrocarbon (BTEX, TPH and PAH) concentrations in soils contaminated with weathered oil product. This focus reflects the fact that (i) many types of PHCs are amenable to microbial degradation; (ii) the phytoremediation of organic contaminants often involves enhanced microbial degradation in the rhizosphere; and (iii) there are an estimated 200,000 PHC-contaminated sites in the Prairie provinces alone. Research during the past decade has attempted to assess the utility of plants in a remediation capacity under prevailing Canadian environmental conditions and associated regulatory oversight. The results of this work indicate that to fully exploit and use phytoremediation we need to gain a better understanding of: (i) the pool of phytoremediation species found in Canada; (ii) how phytoremediation operates under unique Canadian climatic conditions; (iii) the mechanisms employed by phytoremediator plants to restore contaminated sites; and (iv) the agronomic requirements needed to maximize phytoremediation as an efficient and cost-effective cleanup technology. So, while there is clear recognition that phytotechnologies have the potential to play an important role in future remediation strategies in Canada, there remains a critical need for 'field performance data' to verify this potential, as well as to assess its limitations and determine appropriate uses of the newly emerging phytotechnologies.

To address this need, field-scale assessments of plant-based bioremediation have been conducted at sites impacted with weathered hydrocarbons in the oil and gas producing regions of Saskatchewan and Alberta. The objective of this study was to assess and demonstrate the utility of phytoremediation as a means of reducing petroleum hydrocarbon levels in oil-contaminated soils to environmentally acceptable endpoints. Here, we describe a 3-yr study established at a former tank battery near Bruderheim, Alberta.

Methods
Site description
A field site was established in Bruderheim, AB in the spring of 2003. The site consisted of oil-impacted soil from a tank battery (formerly at the same location). The experimental design for the Bruderheim site was a

randomized complete block (RCBD) with four treatments replicated four times (see Figure 1). Protocols used to evaluate the effectiveness of the phytotechnology at this site were adapted from those described in the P*hytoremediation of Petroleum Hydrocarbons in Soil Field Study Protocol* developed by the USEPA Remediation Technologies Development Forum (RTDF)–Phytoremediation of Organics Action Team (http://www.rtdf.org/public/phyto/phytodoc.htm).



Trt 1: unfertilized (gypsum), unplanted

Trt 2: fertilized, unplanted

Trt 3: fertilized, planted (RTDF mix): creeping red fescue (60%); yellow sweet clover (25%); perennial ryegrass (15%)

Trt 4: fertilized, planted (USK mix): slender wheatgrass (20%); western wheatgrass (20%); Altai wild rye (20%); red clover (20%), Nuttall's salt-meadow grass (20%)

Figure 1. Plot plan or the Bruderheim phytoremediation site.

The site consists of one set (n = 4) of unfertilized/unplanted control plots, one set of fertilized/unplanted control plots, and two sets of fertilized/planted treatment plots. One set of the treatment plots was seeded with a standard (RTDF) plant mix; the second set of treatment plots was seeded with a locally optimized mix of local native/adapted species selected from the plant screening program at the University of Saskatchewan. Individual research plots were 6.1m × 6.1m.

Plots receiving the standard (RTDF) plant mix were seeded with creeping red fescue (47 kg/ha), yellow sweet clover (19 kg/ha), and perennial ryegrass (12 kg/ha). Plots receiving the localized (University of Saskatchewan; USK) plant mix were seeded with slender wheat grass (51 kg/ha), western wheatgrass (130 kg/ha), Altai wild rye (123 kg/ha), red clover (23 kg/ha), and Nuttall's salt meadow grass (19 kg/ha). Because germination rates are generally lower in PHC-contaminated soil than in uncontaminated soil, all plant species were seeded at double the recommended rate.

Soil sampling and analyses

Soil characterization and fertility assessments were carried out at the start of the growing season using standard methods (Carter 1993). Plant assessments (percent cover, shoot height, rooting depth & density) were carried out at the end of each growing season, with hydrocarbon analysis of plant tissues being conducted in the last year (i.e., at t3) only. Soil and plant samples were analyzed for PHCs using accelerated solvent extraction (modified EPA Method 3541) followed by analysis for the following target classes: (i) total petroleum hydrocarbons (TPH) by GC-FID (EPA Method 8015); PAHs by GC-MS (EPA Method 8270) ; (ii) CCME PHC-fractions by GC-FID (fractions F1–F4) and GC-MS (fraction F1-BTEX) (Reference Method for the Canada-Wide Standard for Petroleum Hydrocarbons in Soil - Tier 1 Method; CCME, 2001); and (iii) biomarker steranes and triterpanes (e.g., hopane or norhopane) by GC-MS (modified EPA Method 8270).

A thin-walled, split-core sampler tube fitted with a stainless steel liner was used to collect soil samples. Eight random sub-samples from each treatment plot were combined to make one composite sample per plot.

Replicate (n = 5) samples of each composite soil were packed into 250-mL wide-mouth, clear-glass jars with Teflon-lined polypropylene lids (e.g., VWR TraceClean™–QA), stored on ice in a cooler, and transported to the University of Saskatchewan where they were placed into a -20°C freezer and stored till they were analyzed using the methods described above.

Results

Plant assessments

Ground cover in the planted treatment plots (Trt. 3 & 4) ranged from about 75-90% at the end of the first growing season (2003), increasing to about 96–99% at the end of the third growing season (2005). Compositional changes in the plant communities were observed in both of the planted treatments. Plots seeded with the RTDF mix (Trt. 3) showed a small but significant increase in percent cover by the creeping red fescue, with a concomitant decrease in percent cover by the perennial ryegrass. Changes in species composition were more noticeable in the plots seeded with the USK mix (Trt. 4), with the slender and western wheatgrasses increasing their coverage–primarily by out-competing the Altai wildrye.

Total above-ground biomass production in both planted treatments was significantly greater during the second season than the first season, though differences between the treatments were generally small. During the third season, the plots were mowed without the knowledge (or consent) of the researchers—resulting in an apparent decrease in total biomass production. Root production in the planted treatment plots generally increased with time, reflecting increases in both plant cover and growth during the second and third growing seasons.

PHC Degradation

Initial soil characterization of the Bruderheim site revealed that (i) the TPH concentration in the soil averaged 2148 mg/kg in the surface soil (0-15 cm) and 1939 mg/kg in the subsurface soil (15-45 cm); (ii) BTEX compounds were not present at detectable levels; (iii) concentrations of the F2 (C10-C16) and F3 (C16-C34) PHC-fractions exceeded the Canadian soil quality guidelines (SQG) for a coarse-textured agricultural soil; (iv) naphthalene, phenanthrene and pyrene were the only PAHs detected in the soil, and only phenanthrene and pyrene exceeded the SQG; and (v) the soil was alkaline with a sodium adsorption ratio (SAR) that was slightly greater than the SQG, though the soil was not considered saline. The primary soil chemical indicators used to describe the Bruderheim soil are summarized in Table 1.

Upon completion of the third growing season, TPH concentrations averaged across the site had been reduced to 815 mg/kg in the surface (0-15 cm) soil and 701 mg/kg in the subsurface (15-45 cm) soil. Reductions in PHC concentration were observed in all four CCME fractions, with reductions in the F2 fraction resulting in a final concentration that was 40-60% below than the SQG. Significant reductions also were observed for the F3 fraction, though the final concentration (ca. 500 mg/kg) still exceeded the SQG for a coarse-textured agricultural soil. The change in PHC concentration with time exhibited a similar pattern in all four treatment plots, though reductions in the F2 fraction generally occurred more rapidly in the planted treatments. Reductions in the F4 fraction also were generally greater in the planted treatments.

Reductions in PHC concentrations were generally greater in the plots amended with fertilizer and compost and were slightly greater in the planted plots than in the unplanted plots. Because of the rather high degree of spatial variability associated with the PHC determinations, statistical significance was not observed. Likewise, there were no significant differences between the site-specific (USK) plant mix and the standard (RTDF) plant mix, though this presumably reflects the fact that the RTDF mix consisted of plant varieties that were well adapted to the Bruderheim area. PAH concentrations also decreased significantly after three years (Table 1), and were well below the SQG upon completion of the study.

BTEX compounds were not determined at the final sampling, reflecting the fact that they did not exceed the SQGs at the start of the study. Analysis of a subset of the above-ground biomass from the planted treatments failed to detect any PHCs in the plant tissue. This is in keeping with the vast majority of the published literature, which indicates that plant uptake of PHCs, and most PAHs, during phytoremediation are negligible. As a result, a detailed analysis of the plant tissues was not undertaken.

Table 1. Primary soil chemical indicators [petroleum hydrocarbons (PHCs), polyaromatic hydrocarbons (PAHs), trace metals, and salinity indices] measured in the surface (0–15 cm) and sub-surface (15–45 cm) soils from the phytoremediation site at Bruderheim, AB. Values in parentheses are the standard deviation from the mean.

Soil Parameter	SQG* (mg/kg)	--- Initial (t_0) Conc. --- (mg/kg)		--- Final (t_3) Conc. --- (mg/kg)	
		(0–15 cm)	(15–45 cm)	(0–15 cm)	(15–45 cm)
PHCs					
F1 (C6–C10)	30	1.44 (1.79)	0.12 (0.29)	0.03 (0.04)	0.07 (0.19)
F2 (C10–C16)	150	203 (95)	192 (164)	89.4 (62.5)	53.6 (54.7)
F3 (C16–C34)	400	1351 (567)	1369 (589)	510 (252)	500 (69.8)
F4 (C34–C50)	2800	593 (268)	378 (189)	216 (159)	147 (116)
BTEX					
Benzene	0.13	BDL†	BDL	ND‡	ND
Toluene	0.16	BDL	0.02	ND	ND
Ethylbenzene	0.36	BDL	BDL	ND	ND
Xylenes	14	BDL	0.01	ND	ND
PAHs§					
Naphthalene	0.1	0.01 (0.01)		0.01 (0.01)	BDL
Phenanthrene	0.1	0.14 (0.14)		0.01 (0.01)	0.01 (0.01)
Pyrene	0.1	0.26 (0.09)		BDL	0.05 (0.02)
pH	6–8	8.0 (0.2)¥		8.0 (0.2)	8.1 (0.1)
EC (ds/m)	2	1.1 (0.5)¥		0.4 (0.1)	0.4 (0.1)
SAR	5	5.9 (1.1)¥		3.5 (1.0)	4.4 (0.8)

* Canadian Soil Quality Guideline (CCME, 2004 Update): Land use = agricultural; Soil texture = coarse-grained.
† Below detection limit.
‡ Not determined.
§ No other priority PAHs were present in the soil.
¥ Composite sample for the 0–45 cm depth.

Conclusion

Significant ($P \leq 0.10$) reductions in TPH and the CCME PHC-fractions were observed during the three years of field trials at the Husky Energy site near Bruderheim, AB. Reductions in the F2 (C10-C16) fraction, phenanthrene and pyrene brought the final concentrations of these compounds to levels below those identified in the Canadian Soil Quality Guidelines as needing further remedial action. Despite significant (*ca.* 62%) reductions in the F3 (C16-C34) fraction, final concentrations of this fraction still exceeded the SQG for a coarse-textured agricultural soil. PHC reductions in the planted and unplanted treatments were generally similar. These results notwithstanding, plant establishment provides the additional benefits of enhanced soil stabilization and erosion and runoff control.

References

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