PhytoPet© – A Database of Plants that Play a Role in the Phytoremediation of Petroleum Hydrocarbons

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Abstract

Phytoremediation (i.e., plant–assisted bioremediation) of hydrocarbon contaminated soils is a steadily evolving technology that shows promise as an effective and low-cost alternative to most engineering techniques and traditional bioremediation methods. Recently, however, Frick et al. (1999a, 1999b) identified several significant "research gaps" in the published literature, including the fact that very few studies have been conducted on the phytoremediation of petroleum hydrocarbons under cold climate conditions. The cold climate and short growing season characteristic of the major oil and gas producing regions of western Canada make it particularly important to conduct phytoremediation research on plants adapted to local conditions. These findings underscore the need for new research initiatives to assess the potential of phytoremediation as a method of remediating hydrocarbon contaminated sites in western Canada.

As a result of the general lack of knowledge regarding the selection and availability of plants suitable for phytoremediation under Canadian climatic and ecological conditions, we surveyed the available literature and developed a database (*PhytoPet*©) containing information on plants with a demonstrated potential to phytoremediate or tolerate petroleum hydrocarbons. The *PhytoPet*© database was then used in conjunction with site surveys to develop a catalogue of plants with the potential to phytoremediate hydrocarbon contaminated soils in the Prairie and Boreal Plain Ecozones of western Canada. Here we provide a demonstration of the *PhytoPet*© database.

1.0 Introduction

Phytoremediation, the use of plants for the *in situ* treatment of contaminated soils, is essentially *ecological engineering* which capitalizes on the naturally occurring synergistic relationships among plants, microorganisms, and the environment that have evolved over millions of years. Phytoremediation takes advantage of the fact that plants have extensive rooting systems which explore large volumes of soil, support larger bacterial populations in the rhizosphere (the region immediately surrounding the root) than in the surrounding bulk soil, and produce exudates which can directly affect the activity of the rhizobacterial populations (Anderson et al., 1993; Shimp et al., 1993; Erickson, 1997; Sylvia et al., 1998). Though generally considered a long-term

remediation process limited to soils where the contamination is shallow and occurs at low to medium concentrations, phytoremediation holds significant promise for the cost-effective cleanup of certain types of hazardous wastes including gasoline, diesel fuel, and petroleum hydrocarbons (Cunningham et al. 1995; USEPA, 1998; Siciliano & Germida, 1998).

It is generally agreed that the key processes involved in phytoremediation include (i) the stimulation of rhizobacterial transformations by root exudates and decaying plant matter and by affecting the oxygen regime in the rhizosphere, (ii) the slowing of contaminant transport from the rooting zone as a result of adsorption and/or increased evapotranspiration, and (iii) plant uptake, followed by metabolism, volatilization, or accumulation (Cunningham et al., 1995; Schnoor et al., 1995; Siciliano & Germida, 1998). Despite the flexibility and adaptability that these various plant-associated remediation pathways provide, it is the interactions between these pathways as well as the biochemical and ecological interactions between the plant/microbe/environment continuum that give rise to the complexity surrounding phytoremediation. Nevertheless, because of its cost effectiveness, adaptability, and potential as a final *polishing* step to close out sites after other cleanup technologies have been used to treat hotspots, phytoremediation science remains an area of intense interest.

2.0 Database Organization and Search Capabilities

PhytoPet© was compiled using Microsoft Access 97. This platform was chosen because of its widespread use among the various stakeholder groups involved in this project and because of its interchange capability with other database and spreadsheet formats. The purpose of the *PhytoPet*© database is to serve as an inventory of plant species that phytoremediate (or, at the very least, tolerate) petroleum hydrocarbons in terrestrial and wetland environments. Information in the database was compiled by first conducting an extensive computerized search of several public access databases and commercial abstracting services. Key search words and phrases included: phytoremediation, hydrocarbons, petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAH), BTEX compounds, organic contaminants, bioremediation, biodegradation, biotransformation, rhizosphere biodegradation, phytoextraction, phytovolatilization, and natural attenuation. Only published studies reporting a demonstrated ability of one or more plants to phytoremediate or tolerate petroleum hydrocarbons were included in the database.

Information presented in the database is grouped into one of three categories: *summary information*, *experimental data*, and *plant specific data* (Table 1). S*ummary information* provides a brief description of the plant and its mechanism of phytoremediation. The *experimental data* sections provide a detailed summary of the experimental conditions found in each case study included in the database.

Table 1 Information Contained in the *PhytoPet*© Database

Summary Information	Experimental Data	Plant specific Data
▪ Common name of plant	- - - - - *Experimental Data (1)* - - - - -	- - - - - *Plant Description & Habitat* - - - - -
▪ Scientific name of plant	▪ Laboratory or field study	▪ Common & scientific names
▪ Cultivar, strain, or code	▪ Duration of experiment	▪ Synonym
▪ Demonstrated ability of plant to phytoremediate or tolerate hydrocarbon	▪ Soil characteristics	▪ Family
▪ Mechanism of phytoremediation	▪ Age of plant at first exposure	▪ Demonstrated ability of plant to phytoremediate or tolerate hydrocarbon
▪ Types of microorganisms associated with plant	▪ Initial hydrocarbon concentration	▪ Growth habit
	▪ Post-experiment concentration and/or conditions	▪ Morphology
		▪ Life cycle
	- - - - - *Experimental Data (2)* - - - - -	▪ Primary habitat
	▪ Storage sites in plant	▪ Salinity tolerance
	▪ Fertility/management requirements	
	▪ Additional notes	- - - - *Additional Information & References* - - - -
	▪ Reference	▪ Western Canadian occurrence
		▪ North American occurrence
		▪ World range
		▪ Cultural information
		▪ Impact description
		▪ Natural history notes
		▪ Other species in genus
		▪ Additional notes
		▪ References

(NOTE: as of November 9, 1999 information from 34 such cases had been compiled.) The *plant specific data*, include information on the taxonomy, habitat, biology, and distribution of each plant in the database.

Upon opening the phytopet.mdb file in Microsoft Access 97 (ver. SR-2 or later), the user is presented with the main menu window (Figure 1). Four option buttons (i.e., search filters) in the main menu allow the user to search the experimental data by selecting either a specific *petroleum hydrocarbon*, an *individual plant species* (using either the common or scientific name), a *plant group* (based on whether the species phytoremediate or only tolerate petroleum hydrocarbons), or the primary *phytoremediation mechanism* of the plant (e.g., accumulation, rhizosphere degradation, containment, or phytovolatilization). In addition, species-specific data on each of the 62 plants included in the database can be accessed through the *plant details* option button. The complete list of *references* used to compile the database also can be accessed from the main menu. Moreover, regardless of which search filter is used to explore the database, the user can obtain a printout of all information displayed on-screen.

Figure 1 *PhytoPet*© database window (Microsoft Access 97) showing the main menu

An additional feature of the database involves the *multiple queries* option (Figure 2). This option allows the user to generate a list of plants that have several characteristics in common, such as habitat, salinity tolerance, the ability to either

tolerate or phytoremediate specific hydrocarbons, phytoremediation mechanism, and the occurrence of the plant in Western Canada. Once a plant list has been generated, a printout of the list can be obtained and the user can then return to the main menu to obtain the relevant botanical information for each plant species and examine specific information relating to the experimental conditions under which the plant's phytoremediation potential was demonstrated (e.g., type and concentration of contaminant, phytoremediation mechanism, special requirements, etc.).

Figure 2 ***PhytoPet*© database window (Microsoft Access 97) showing the *multiple queries* menu**

2.1 An Example of a Multiple Queries Search of the *PhytoPet*© Database

The major oil and gas producing regions of western Canada occur in the Prairie Ecozone (characterized by a climate that ranges from semiarid to humid continental and typically involves long, cold winters and short, very warm summers) and the Boreal Plain Ecozone (characterized by a climate that involves long, cold, snowy winters and short, warm, moist summers) (Acton *et al.*, 1998). Not surprisingly, therefore, the identification of plants that (i) have a demonstrated phytoremediation potential and (ii) can tolerate the relatively harsh climatic conditions characteristic of the region is one of the major challenges facing the adoption of phytoremediation strategies for the reclamation of petroleum contaminated sites in western Canada.

A multiple queries search of the *PhytoPet*© database was conducted for "*terrestrial plants* with a demonstrated ability to *phytoremediate* hydrocarbon contaminated soils and which are *native to western Canada*". This search generated a list of 11 plant species capable of degrading (or assisting in the degradation of) a variety of petroleum hydrocarbons (Table 2), and which may have potential for phytoremediation efforts in the Prairie and Boreal Plain Ecozones.

Table 2 Plants Native to Western Canada and with a Demonstrated Ability to Phytoremediate Petroleum Hydrocarbons: Results of a Multiple Queries Search of the *PhytoPet*© Database

Plant Common Name (*Genus, Species*) [Family – Growth Form]	**Petroleum Hydrocarbons**	**Mechanism of Phytoremediation**
Western wheatgrass (*Agropyron smithii*) [Gramineae – grass]	chrysene, benzo[*a*]pyrene, benz[*a*]anthracene, dibenz[*a,h*]anthracene	unknown
Big bluestem (*Andropogon gerardi*) [Gramineae – grass]	chrysene, benzo[*a*]pyrene, benz[*a*]anthracene, dibenz[*a,h*]anthracene	unknown
Side oats grama (*Bouteloua curtipendula*) [Gramineae]	chrysene, benzo[*a*]pyrene, benz[*a*]anthracene, dibenz[*a,h*]anthracene	unknown
Blue grama (*Bouteloua gracilis*) [Gramineae – grass]	chrysene, benzo[*a*]pyrene, benz[*a*]anthracene, dibenz[*a,h*]anthracene	unknown
Common buffalograss (*Buchloe dactyloides*) [Gramineae – grass]	naphthalene, fluorene, phenanthrene	unknown
Prairie buffalograss (*Buchloe dactyloides* var. Prairie) [Gramineae – grass]	naphthalene, fluorene, phenanthrene	unknown
Canada wild rye (*Elymus canadensis*) [Gramineae – grass]	chrysene, benzo[*a*]pyrene, benz[*a*]anthracene, dibenz[*a,h*]anthracene	unknown
Red fescue (*Festuca rubra* var. Arctared) [Gramineae – grass]	crude oil and diesel	rhizosphere effect (suspected)
Poplar trees (*Populus deltoides* x *nigra*) [Salicaceae – deciduous tree]	potential to phytoremediate benzene, toluene, *o*-xylene	rhizosphere effect
Little bluestem (*Schizchyrium scoparious* or *Andropogon scoparious*) [Gramineae – grass]	chrysene, benzo[*a*]pyrene, benz[*a*]anthracene, dibenz[*a,h*]anthracene	unknown
Indiangrass (*Sorghastrum nutans*) [Gramineae – grass]	chrysene, benzo[*a*]pyrene, benz[*a*]anthracene, dibenz[*a,h*]anthracene	unknown

3.0 Use of the *PhytoPet*© Database in Conjunction with On-Site Botanical Surveys

It is generally acknowledged that there is little published information regarding the selection and availability of plants suitable for phytoremediation under western Canadian climatic and ecological conditions (Frick et al., 1999a; 1999b). Therefore, botanical surveys of several sites where the soils had been contaminated by oil or gas production wastes or spills were undertaken during the fall of 1999 (Godwin et al., 2000). Plant species catalogued during the botanical surveys were then cross referenced against those in the *PhytoPet*© database to develop a list of plants to be screened for their phytoremediation potential under local soil and environmental conditions.

Though more than 70 plant species were catalogued at the contaminated sites, there were only four matches to plants listed in the *PhytoPet*© database: alfalfa (*Medicago sativa*), common cattail (*Typha latifolia*), quack grass (*Agropyron repens*), and red fescue (*Festuca rubro*). However, an additional 21 plant species (including 16 native species) catalogued at the contaminated sites were found to be related at the genus level to plants listed in the database (Table 3).

Table 3 Plant Species Present at Oil Contaminated Sites in the Prairie and Boreal Plain Ecozones of Alberta and Related Plants Listed in the *PhytoPet*© Database

Genus	Species	
	Site Surveys	*PhytoPet*©
Agropyron	*A. repens*, A. subsecundum, A. trachycaulum*	*A. repens*, A. smithii†, A. desertorum**
Carex	*C. bebbii, C. rostrata,C. siccata*	*C. aquatilis, C. rupestris, C. rotundra*
Elymus	*E. innovatus*	*E. canadensis†*
Hordeum	*H. jubatum*	*H. vulgare*
Medicago	*M. falcata*, M. sativa*†*	*M. sativa*†, M. lupulina†*
Melilotus	*M. alba*, M. officianalis**	*M. altissima*†*
Phalaris	*P. arundinacea*	*P. arundinacea*
Pinus	*P. contorta*	*P. banksiana*
Populus	*P. balsamifera, P. tremuloides*	*P. deltoides†, P. nigra†*
Salix	*S. bebbiana, S. discolor, S. petiolaris*	*S. arctica*
Scirpus	*S. microcarpus*	*S. pungens*
Trifolium	*Trifolium spp.**	*T. hybridum*, T. pratense*,T. repens**
Vicia	*V. americana*	*V. faba**

* Species exotic (non-native) to the Prairie and Boreal Plain Ecozones of Alberta.

† Plant species with a previously demonstrated phytoremediation potential.

In all, the *PhytoPet*© database was used to identify 33 plant species (27 native and

six introduced species) that may have applications for the phytoremediation of hydrocarbon contaminated sites in the Prairie and Boreal Plain Ecozones of western Canada. This list of candidate plants includes 11 species with a previously demonstrated phytoremediation potential (see Table 2) and 22 related species (see Table 3) selected from a catalogue of plant species found growing at hydrocarbon contaminated sites in western Canada. In addition, eight species found to be dominant or codominant at one or more sites (Table 4) – but which were not related to any plant listed in the *PhytoPet*© database – also were added to the list of candidate plants. We are currently in the initial stage of a multi-phase study to assess the phytoremediation potential (and elucidate degradation mechanisms) of these candidate plants under simulated local environmental conditions.

Table 4 Dominant or Codominant Plant Species Present at Oil Contaminated Sites in the Prairie and Boreal Plain Ecozones of Alberta (Plants Not Listed in the *PhytoPet*© Database)

Scientific Name	Common Name	Life Cycle & Growth Habit
*Bromus inermis**	Smooth brome	Perennial grass
*Poa pratensis**	Kentucky bluegrass	Perennial grass
Equisetum arvense	Common Horsetail	Perennial forb
*Galeopsis tetrahit**	Hemp nettle	Annual forb
Calamagrostis canadensis	Marsh reed grass	Perennial grass
*Turaxacum officianale**		Perennial forb
*Phleum pratense**	Timothy	Perennial grass
Alnus crispa	Green alder	Perennial shrub

* Species exotic (non-native) to the Prairie and Boreal Plain Ecozones of Alberta.

4.0 Availability and Limitations of the *PhytoPet*© Database

4.1 Availability of the *PhytoPet*© Database

Version 2.1 of the *PhytoPet*© database is currently available in CD format from the authors. Final release of the database [including the companion reports by Frick et al. (1999b) and Godwin et al. (2000)] is scheduled for mid summer of 2000. Copies of the *PhytoPet*© database and associated reports can be obtained in either printed or CD format (free of charge) from the Department of Soil Science (University of Saskatchewan); Environment Canada; and the Petroleum Technology Alliance Canada (PTAC). A web version of the database (ver. 3.0) and all future updates of the database will be made available through a web site maintained by the Department of Soil Science at the University of Saskatchewan[1].

[1] http://www.ag.usask.ca/departments/scsr/department/index.html.

4.2 Inherent Limitations of the *PhytoPet*© Database

The *PhytoPet*© database was developed as a tool to assist remediation specialists, site owners and managers, and environmental scientists in choosing candidate plants which may be suitable for the phytoremediation of petroleum hydrocarbons. Inevitably, however, some records which should have been included in the database were most likely missed during the initial computerized search of the literature. In addition, because the information entered into the database comes from a variety of sources – each with its own purpose – the specific information required to complete the various data fields (see Table 1) was not always available. With this in mind, several characteristics of the information provided in the database deserve closer attention. First, when considering phytoremediation as a reclamation strategy, stakeholders must consider the climate and soil type in the area they are reclaiming as these factors will influence the effectiveness of the phytoremediation effort (Jackson, 1999). However, the majority of studies included in the database (i.e., ca. 76%) involved only laboratory studies conducted under artificially controlled environmental conditions. Furthermore, only about 40% of the plant species listed in the database have been shown to produce enhanced degradation of the target contaminant; i.e., most of the plants listed in the database have been shown only to tolerate hydrocarbon contamination. Likewise, in only a few instances (i.e., ca. 35% of the 81 plant-hydrocarbon combinations) was there an attempt to determine the degradation mechanism involved in phytoremediation. Accordingly, although the *PhytoPet*© database provides a useful tool for helping to select plants with phytoremediation potential and prioritize the screening of candidate plant species. It is intended to supplement, not supplant, region-specific botanical surveys. Moreover, before any plant species is used in a site remediation project, small-scale field trials should be conducted to validate a plant's phytoremediation potential under local conditions. Preliminary field trials also will help alert users to any possible confounding effects associated with salinity, wetability, and prior herbicide use on plant viability.

4.3 Native vs. Non-Native Plant Species

The U.S. government's Office of Technology Assessment has estimated that 4 to 19% of non-native organisms introduced into natural and agricultural ecosystems in the United States have had a severe negative impact on both the environment and the economy (OTA, 1993). Not surprisingly, therefore, there is much concern among ecologists and naturalists about the use of exotic species as vehicles for the phytoremediation of contaminated sites. Nevertheless, the use of exotic species should not be ruled out without due consideration of the threat they actually pose. (This should include discussions with appropriate regulatory agencies and concerned public organizations about species suitability.) For example, a species such as smooth brome (*Bromus inermis*) is a major threat to native plant communities in the moist grassland regions of the Canadian prairies. It is capable of invading native grass and shrub stands, greatly altering the stand's species composition and structure. However, brome is so

widely spread now that it is found throughout the settled areas of the landscape. Thus, if its phytoremediation potential were to be established, it may be appropriate for use in areas where it is already ubiquitous in the landscape. Even an exotic species that could be considered a threat to native plant communities may still be useful if its use were restricted to areas not adjacent to native plant communities – e.g., the use of alfalfa in highly cultivated areas. Wherever possible, however, native plant species should be given preference over exotics.

5.0 Conclusions

The *PhytoPet*© database was developed as an inventory of plants with a demonstrated ability to phytoremediate or, at the very least, tolerate soils contaminated with petroleum hydrocarbons. As such, the database is expected to provide easy access to a wide range of information and assist in the pre-selection of plants appropriate for the phytoremediation of petroleum hydrocarbons in terrestrial and wetland environments.

The *PhytoPet*© database may prove especially useful when used in conjunction with the *Phytoremediation Decision Tree* (ITRC, 1999) – a tool which uses site-specific information and a flow chart layout to assist site managers in deciding whether phytoremediation is appropriate for a particular site. Once the suitability of a given site for phytoremediation has been established, the *PhytoPet*© database would be used to identify plants with phytoremediation potential for that site.

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