Phytotechnologies

Plant-based Systems for Remediating Oil Impacted Sites

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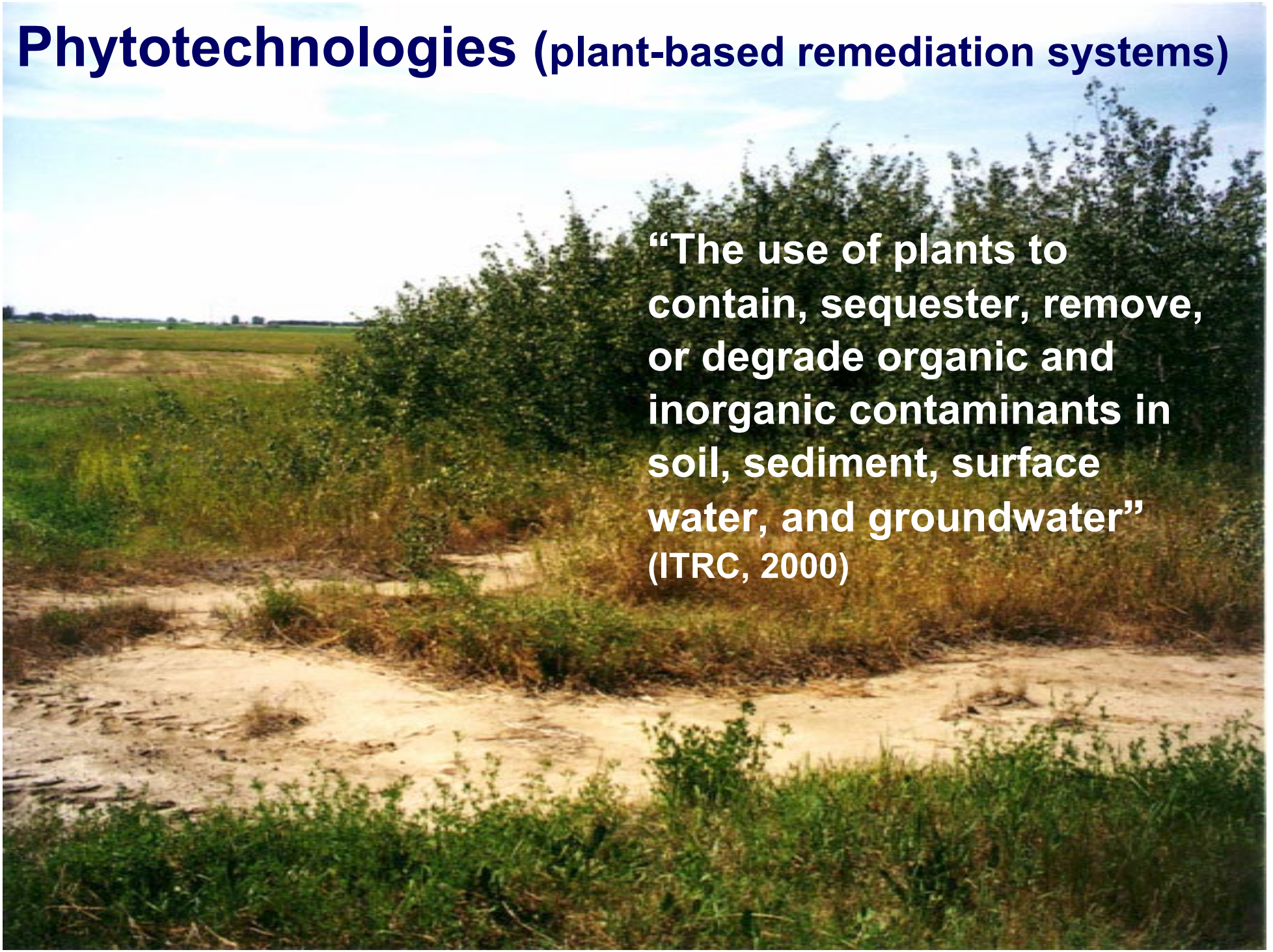
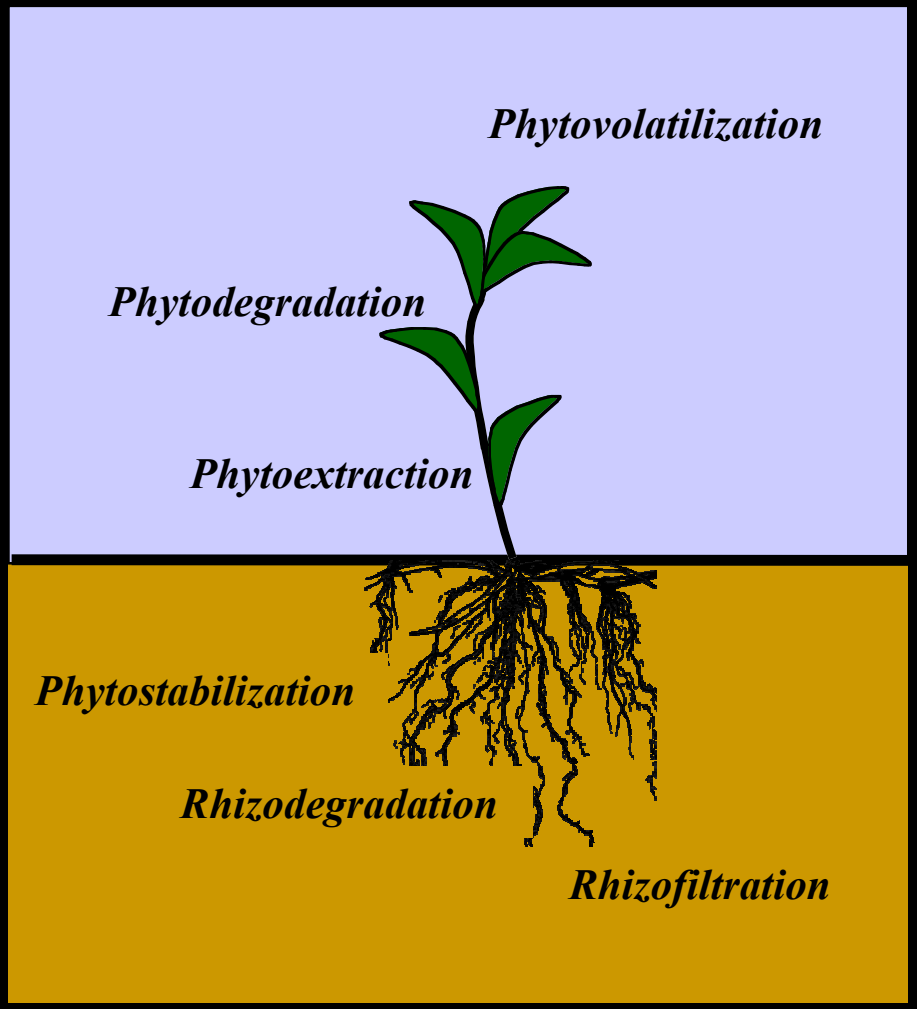
Phytotechnologies (plant-based remediation systems)



"The use of plants to contain, sequester, remove, or degrade organic and inorganic contaminants in soil, sediment, surface water, and groundwater"
(ITRC, 2000)

Mechanisms of phytoremediation



Regions of activity

- Root zone
  - rhizodegradation
  - phytostabilization
  - rhizofiltration
- Plant tissue
  - phytoextraction
  - phytodegradation
  - phytovolatilization

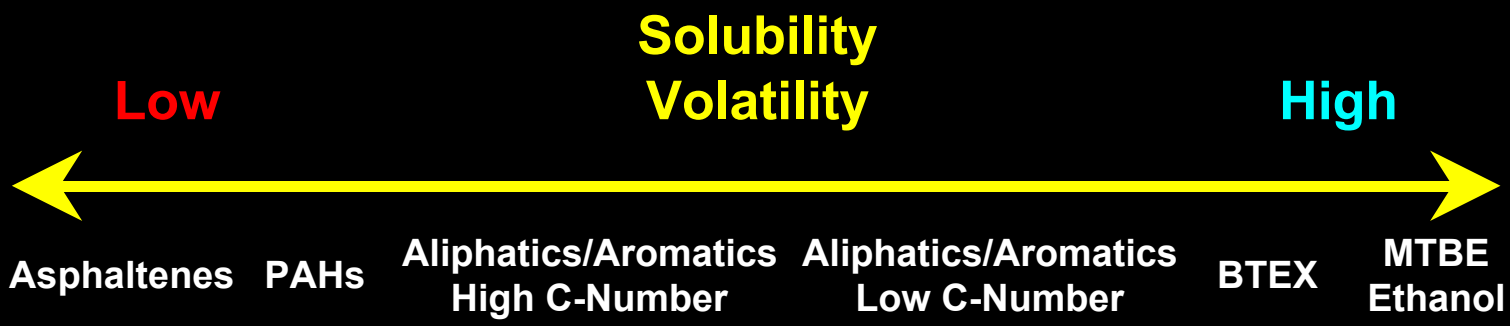
The plant root system

1st contact between the plant and contaminant

All phytotechnologies are dependent on the development of healthy, extensive root systems

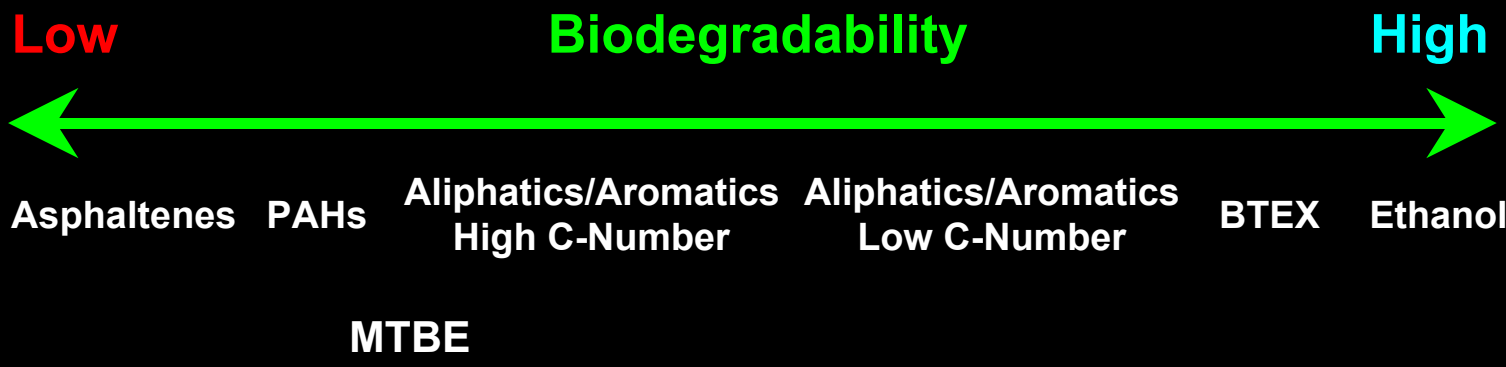
- allows the plant to explore the soil
- affects soil conditions by increasing soil aeration and moderating soil moisture content
- releases exudates that affect microbial activity and numbers
- is ‘home’ to larger, more diverse microbial populations than are present in the bulk soil

Characteristics of PHCs

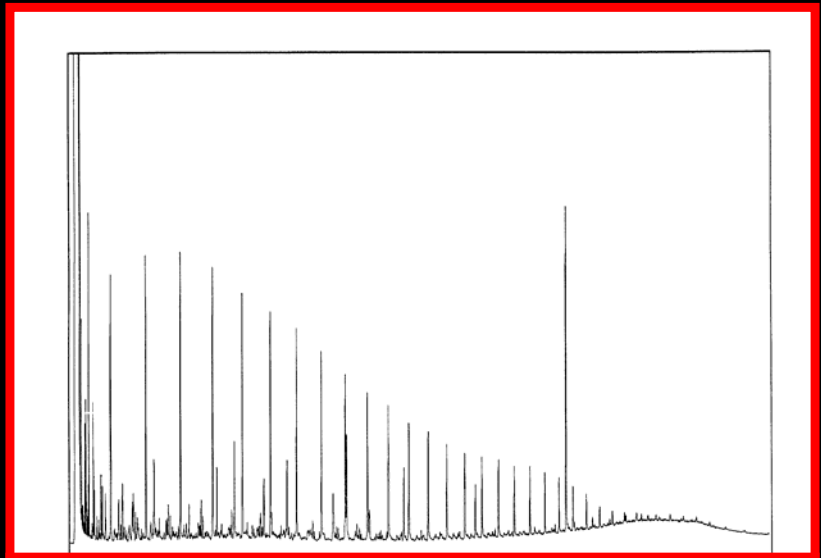


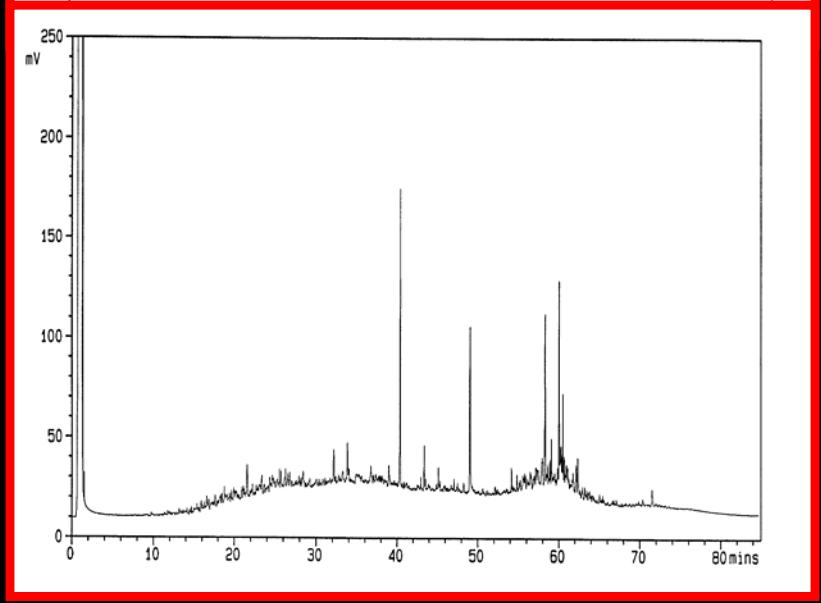
"Heavier" Hydrocarbons

"Lighter" Hydrocarbons



Hydrocarbon degradability





Petroleum hydrocarbons from tank bottoms.

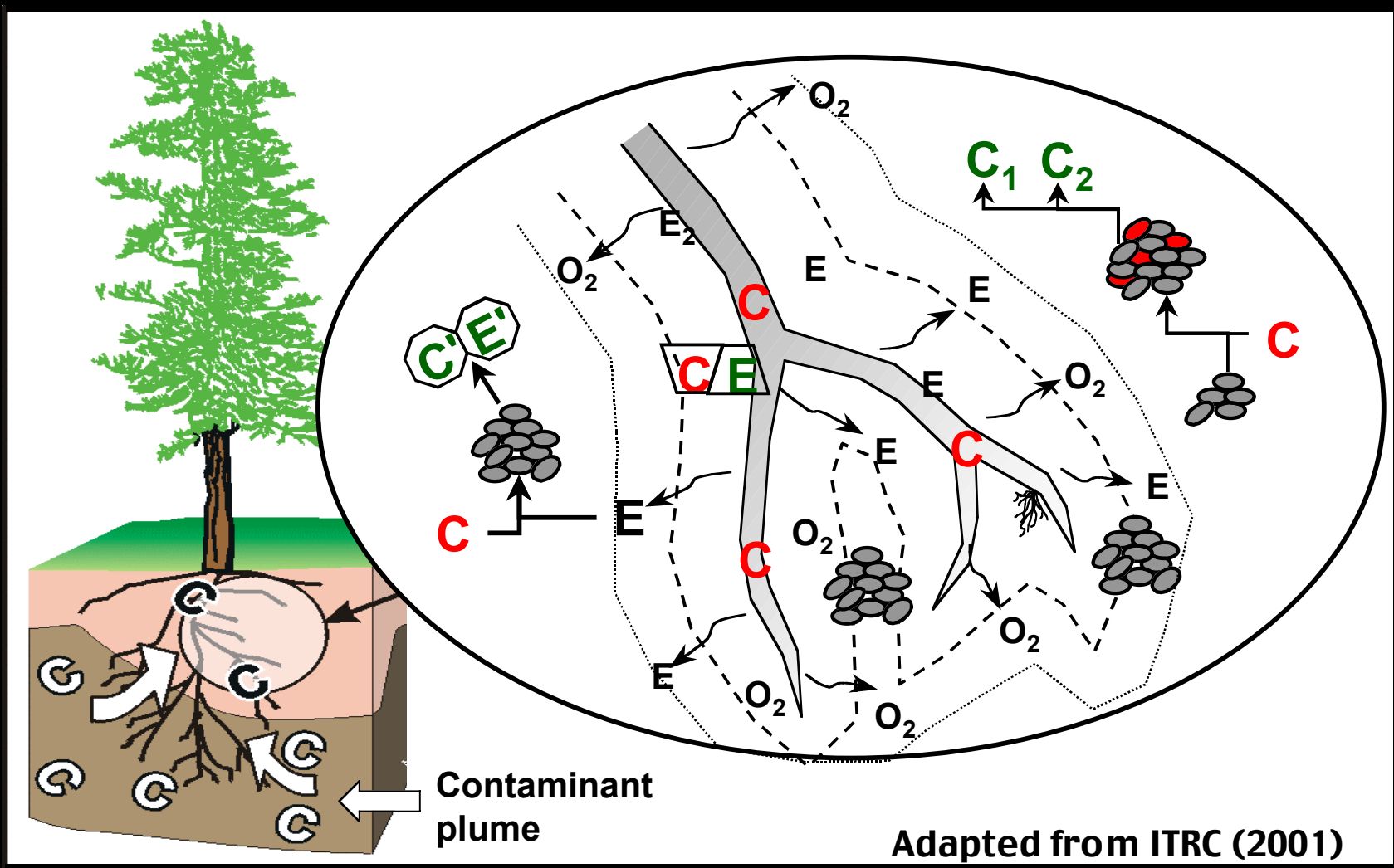
Highly degradable alkanes shown by resolved peaks in chromatogram

Petroleum hydrocarbons from an old spill site.

Few resolved peaks indicate the hydrocarbons have biodegraded.

Phyto in the rhizosphere

Rhizodegradation & Phytostabilization



Adapted from ITRC (2001)

From the laboratory to the field:

An Overview of the U of S Phytoremediation Research Project

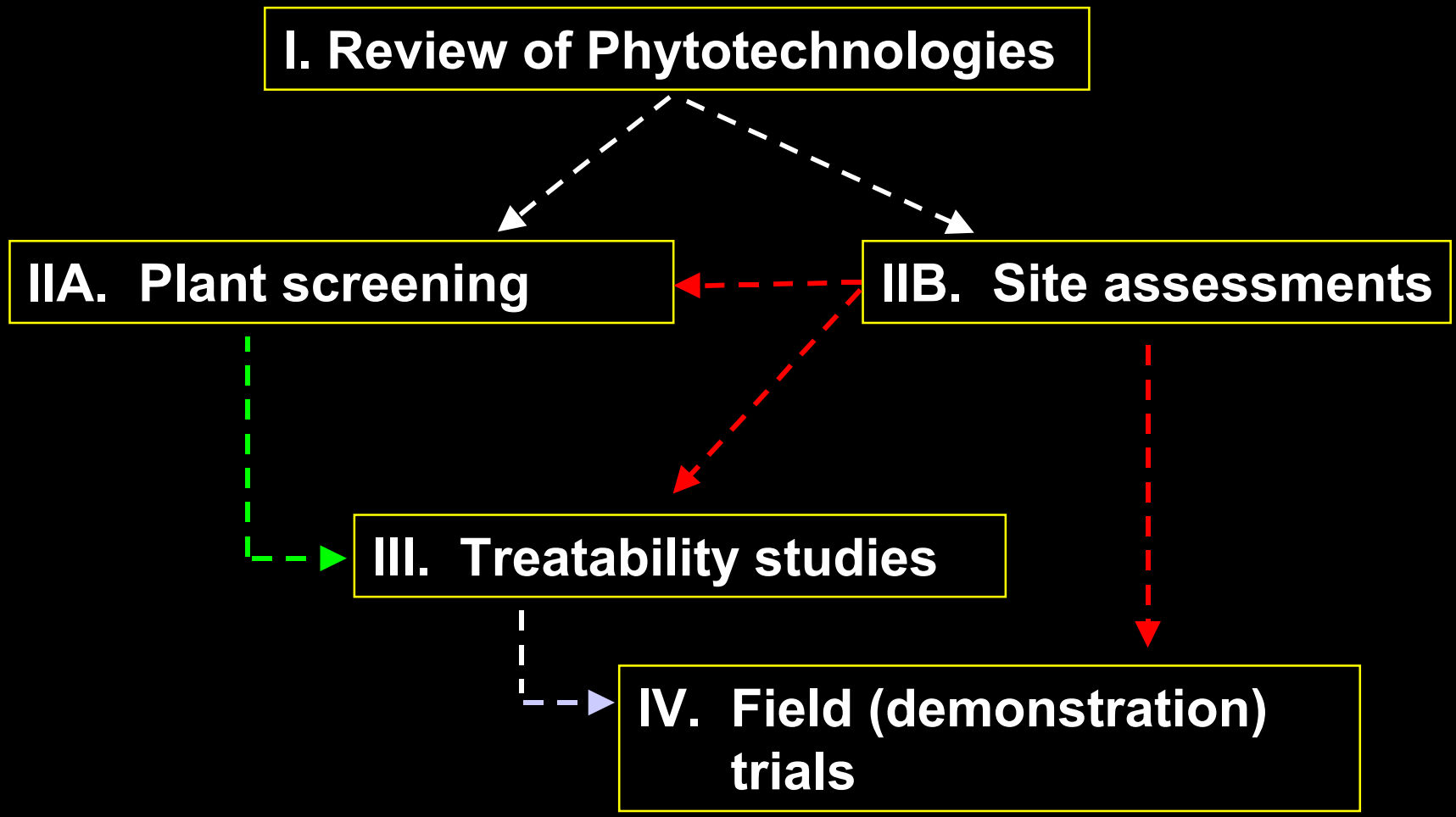
Phytotechnologies for the remediation of oil-impacted soils in western Canada

Scope of the problem in Canada

5,000	contaminated sites owned by Federal government
10,000	abandoned mine sites
6,000	abandoned tailing sites
875 Mt	radioactive mine tailings from uranium mines
100,000	active & abandoned oil/gas drilling sites in the Prairie provinces
29,000	“Brownfield” sites under provincial control

The remediation market in Canada is estimated at $1.5 to $3 billion dollars and “offers good opportunities for growth”

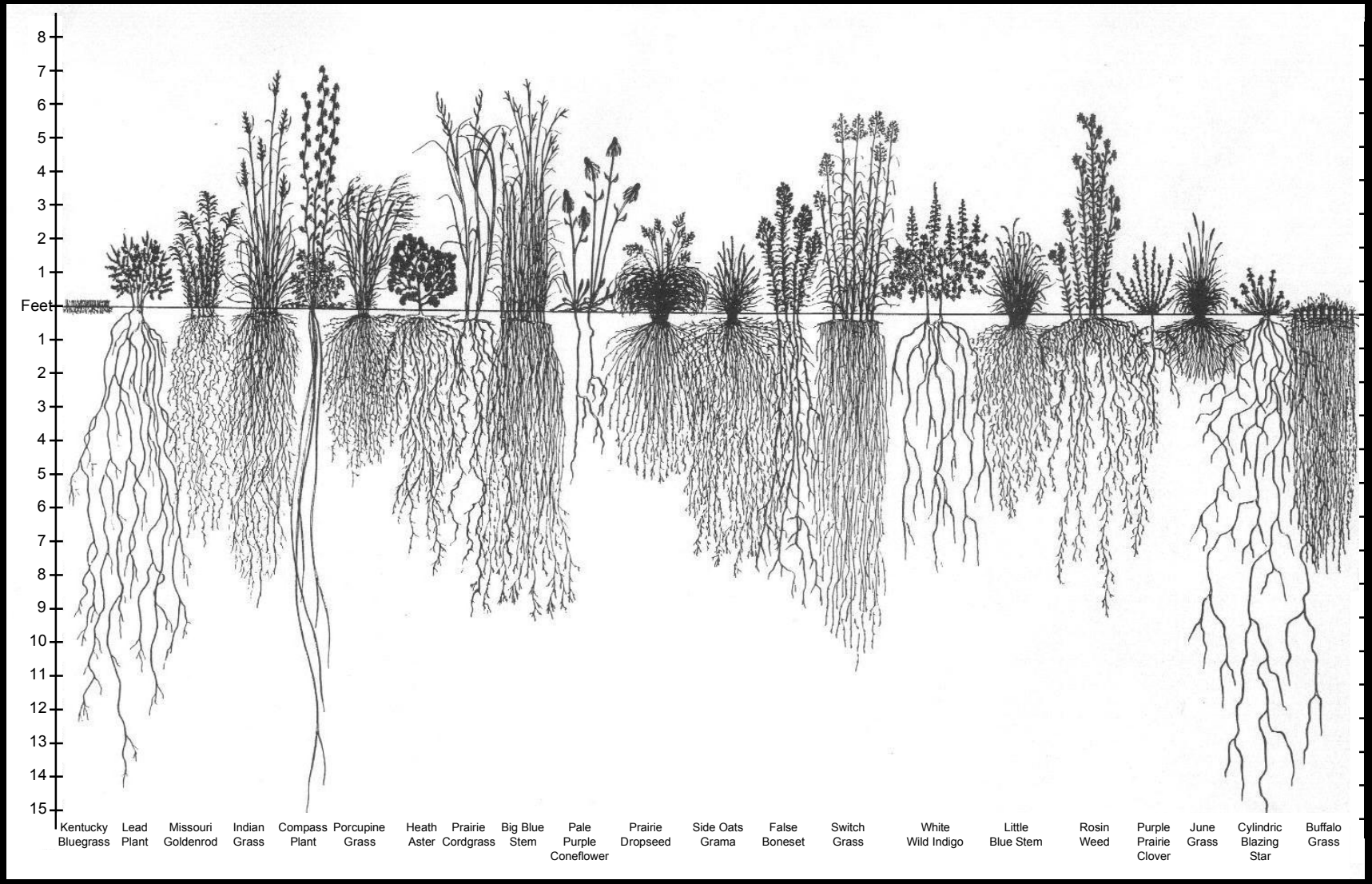
Goal: Evaluate the effectiveness of phytotechnologies as a means of reducing hydrocarbon concentrations in soils contaminated with weathered crude oils and refined oil products.



Technology Assessment

- Objective
  - Examine the state of the art to determine whether phytoremediation is a valid technology for the in situ treatment of hydrocarbon-contaminated sites in Canada
- Conclusion
  - Research gaps exist with regards to phytoremediation in cold regions
  - Few plants adapted to the climatic conditions of western Canada have been identified
  - Positive results in laboratory studies are difficult to replicate in the field
  - Phytoremediation is well-suited for large and/or remote sites where traditional methods are not cost-effective or practicable

Plant screening: Deep rooted grasses



Source: www.epa.gov/greenacres/

Site Assessments

Identify potential phytoremediator plants

Selected 57 plant species for initial screening

Plant screening: Treatability

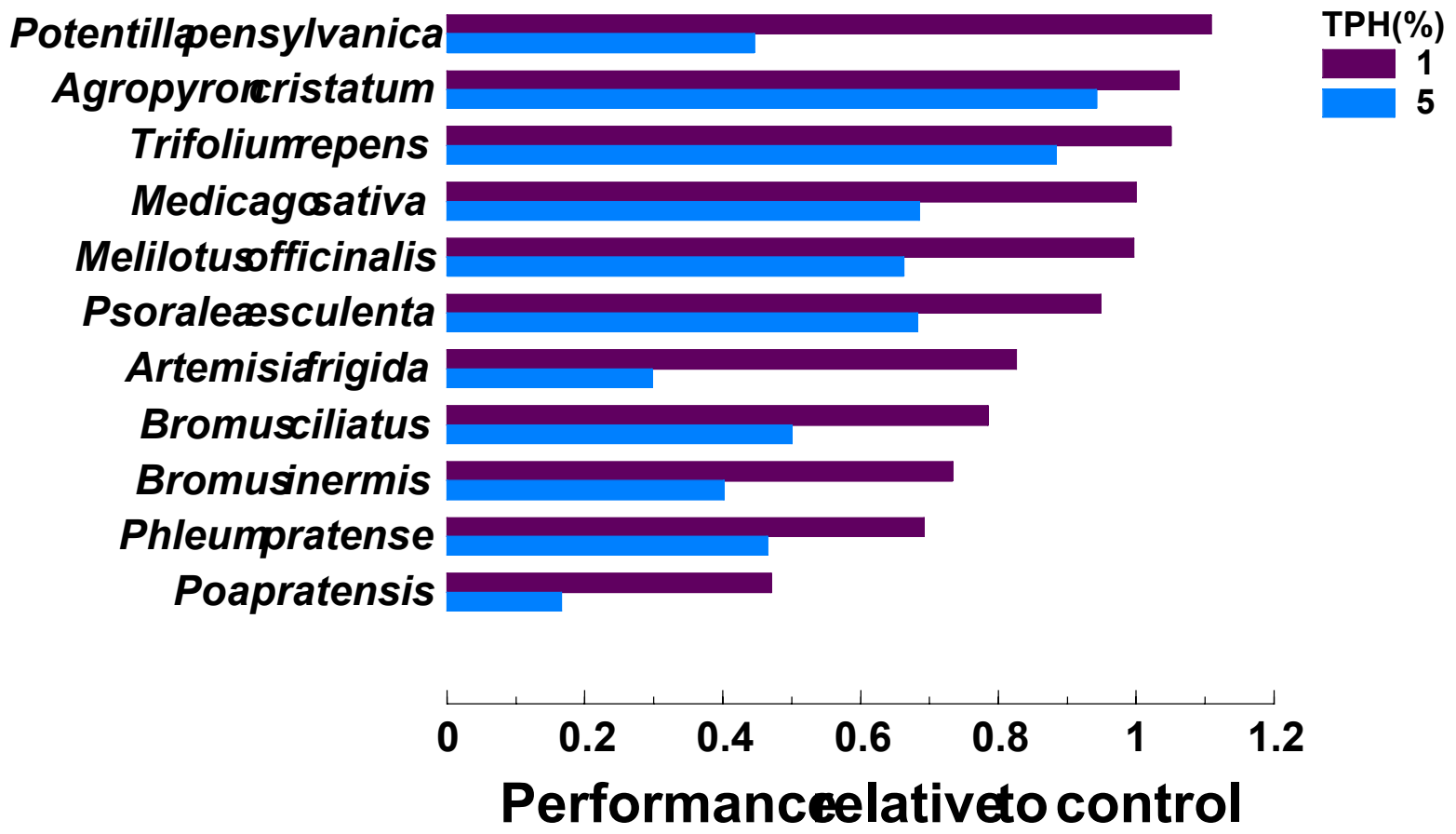
- Objective
  - evaluate the plant growth characteristics and efficacy of potential phytoremediator plants adapted to western Canadian conditions
- Methodology
  - germination tests (seed viability)
  - 28-day bioassay

    suvival and biomass production
  - 56-day bioassay

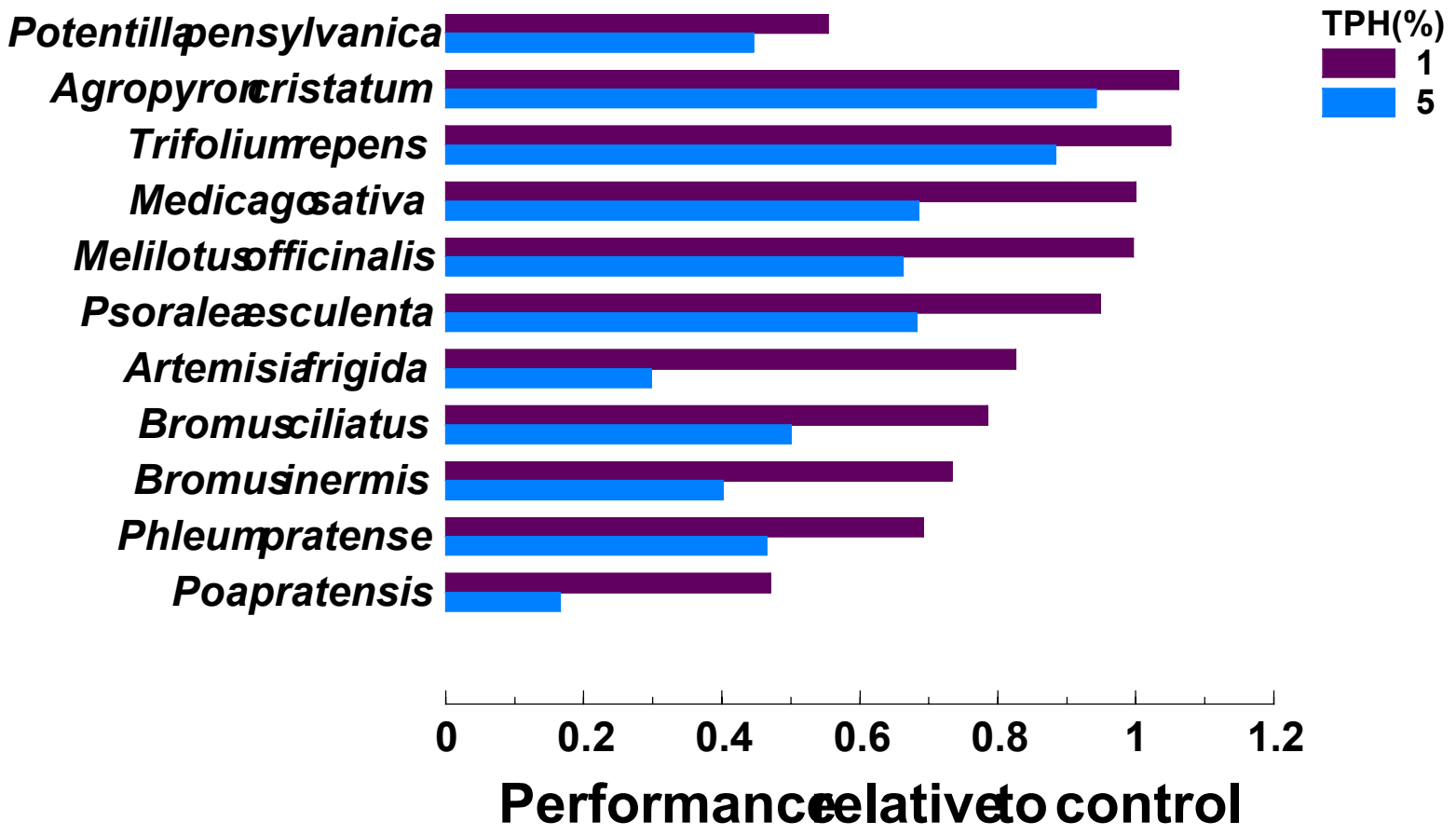
    evaluate the effects of increasing concentrations of crude oil on plant survival and biomass production

    screen plants in soils contaminated with weathered crude

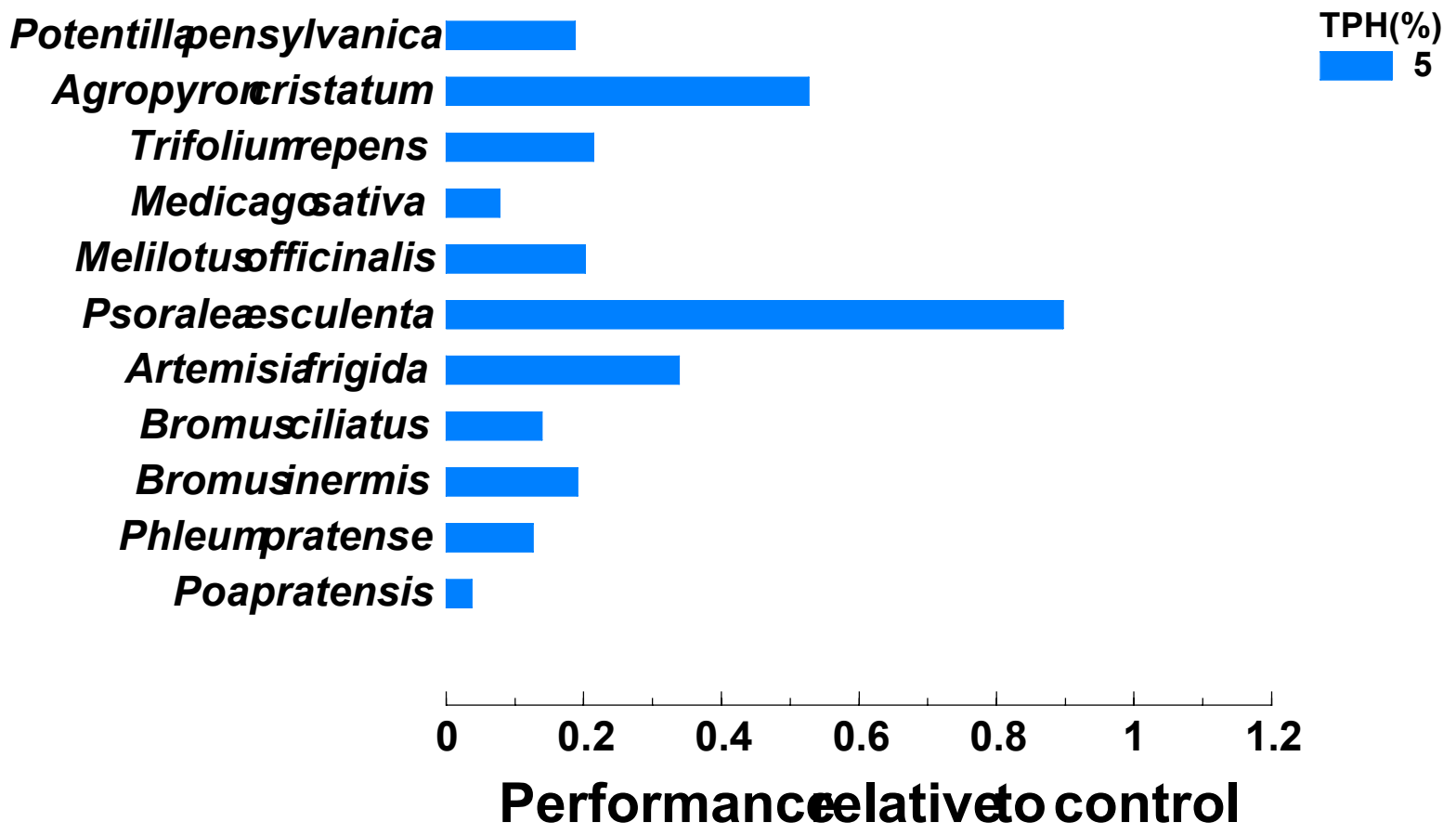
Seed germination & plant survival



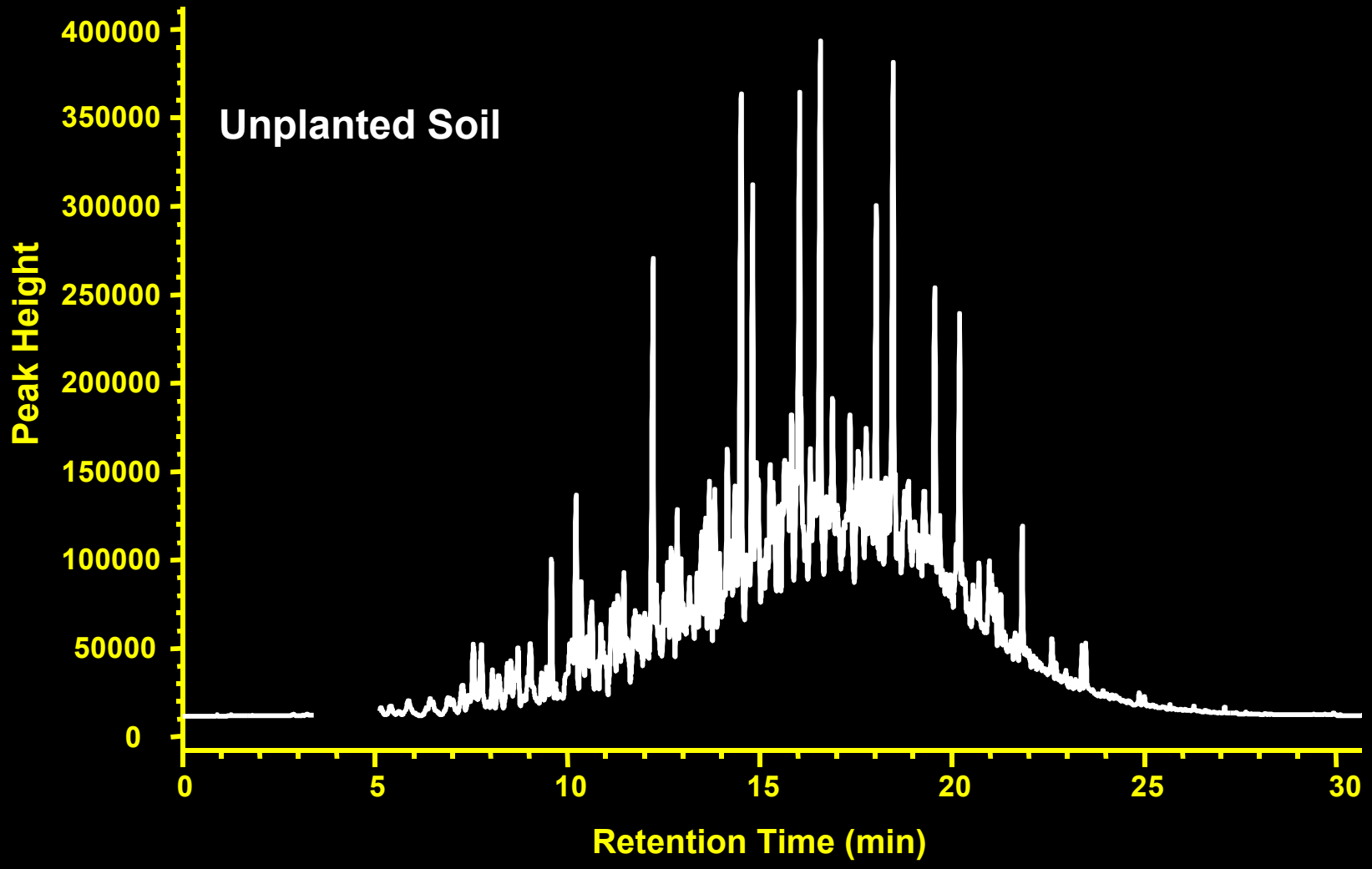
Total plant biomass



Root biomass



PHC “fingerprinting”



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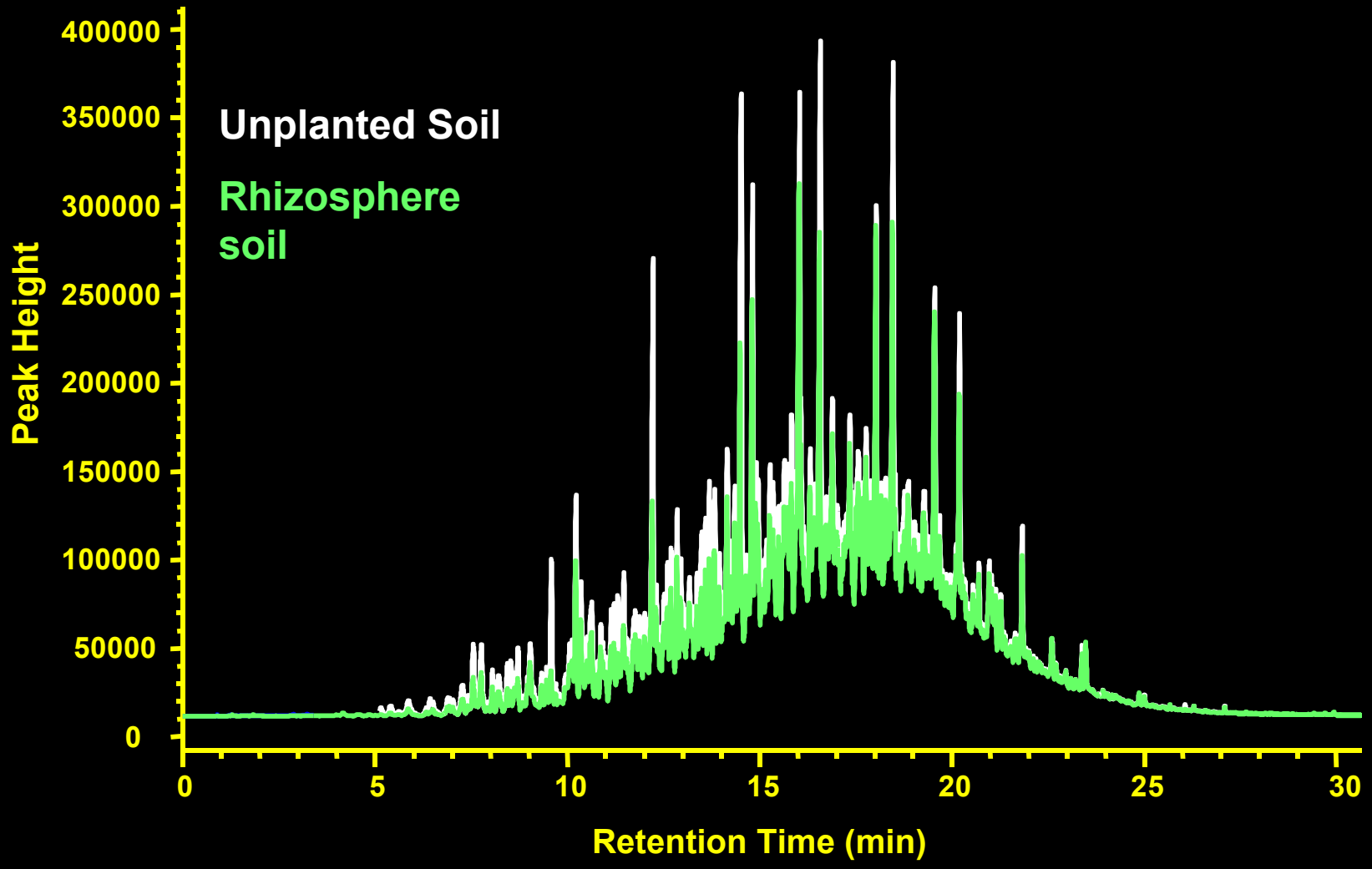
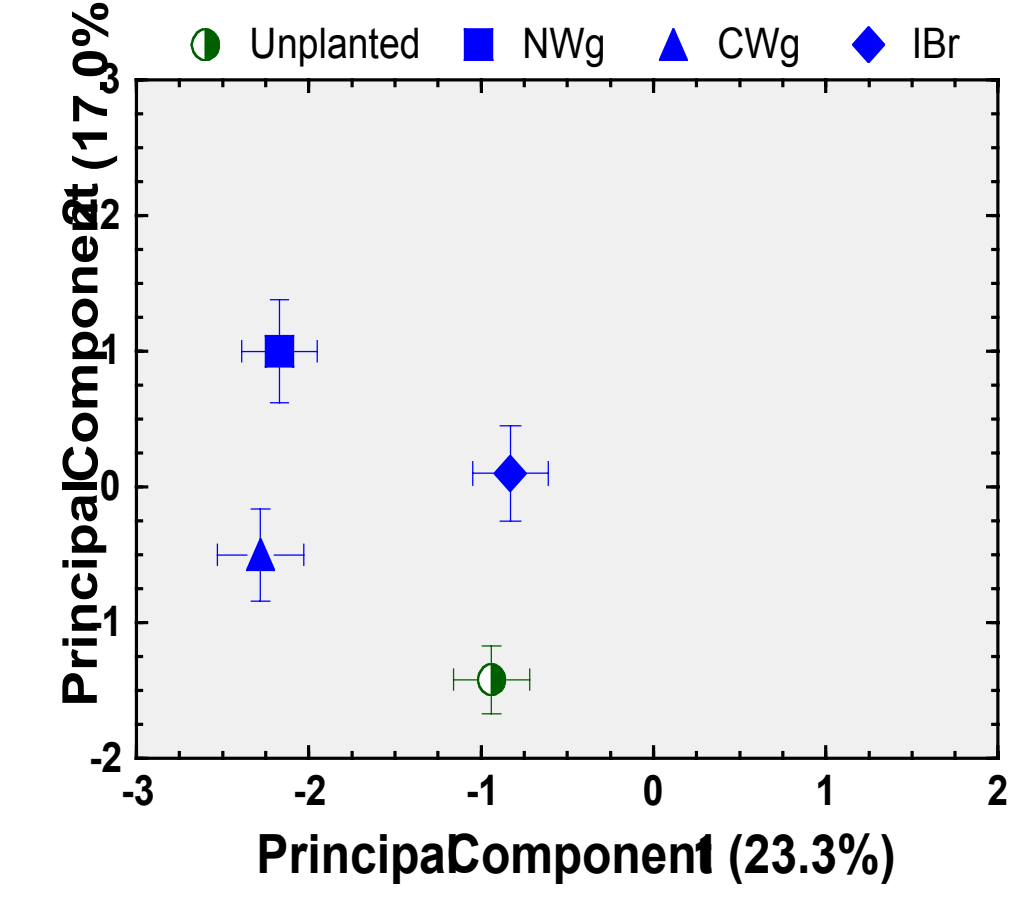
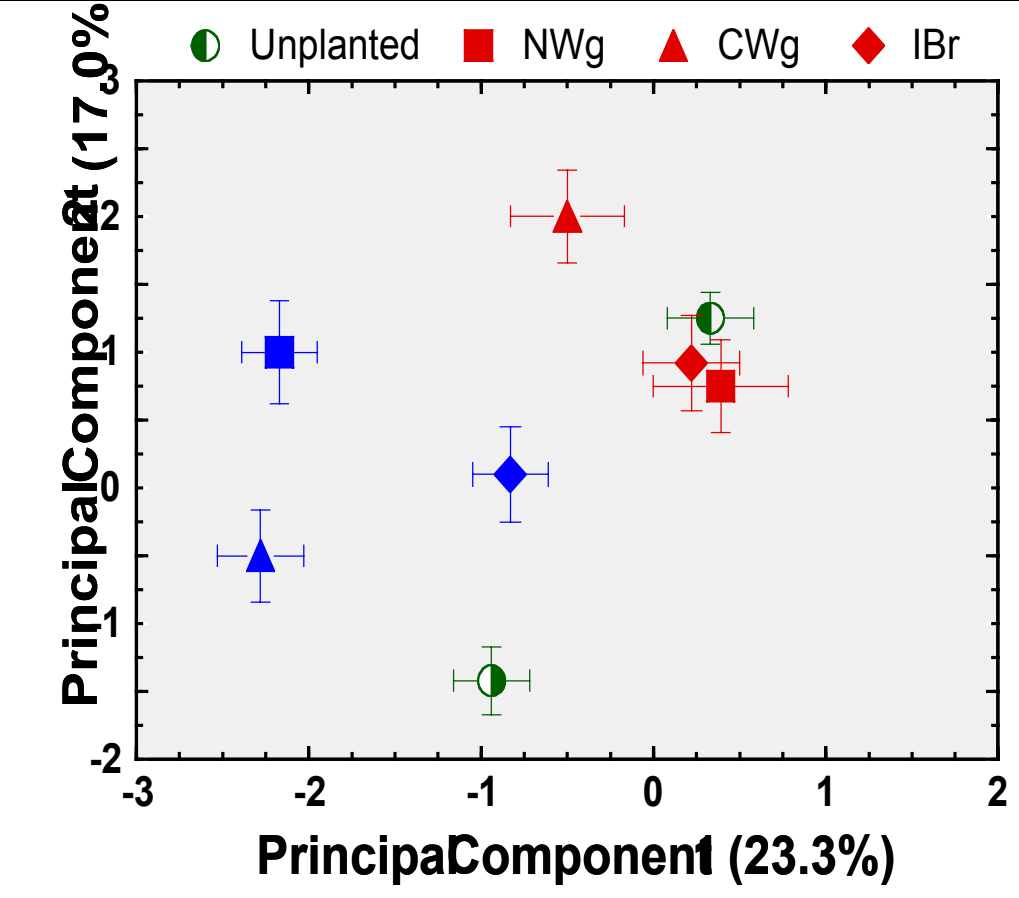


Plant Effects on Microbial Diversity & Function



Denaturing Gradient Gel Electrophoresis (DGGE) shows a shift in genetic diversity of the microbial communities associated with different plant species

Plant Effects on Microbial Diversity & Function



Denaturing Gradient Gel Electrophoresis (DGGE) shows a shift in genetic diversity of the microbial communities associated with different plant species

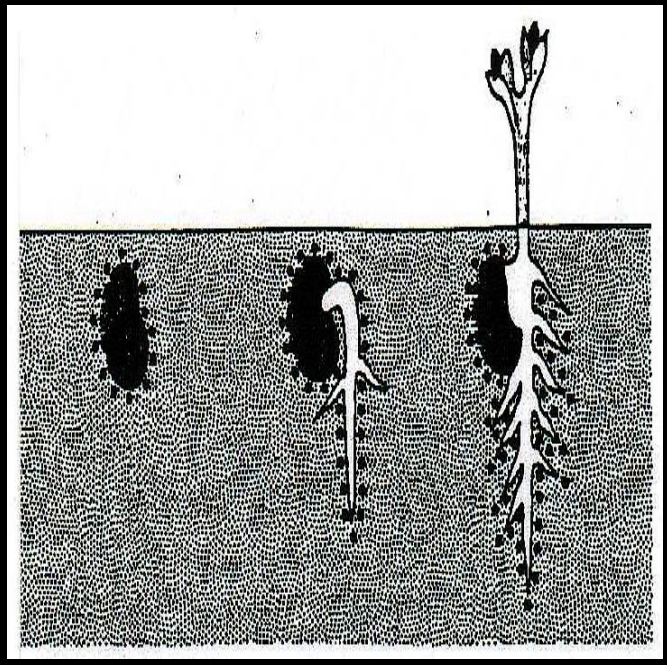
Microbial communities also respond to changes in environment

PHC–degrading Microorganisms

Hydrocarbon-degraders occur naturally in most soils, but are generally present in greater numbers in contaminated soil

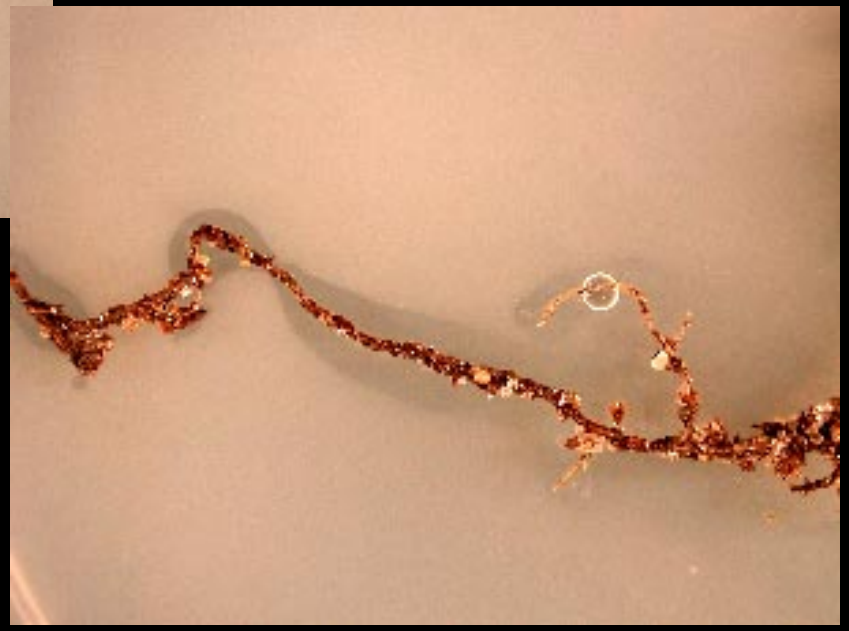
Isolation

Introductio



Uninoculated

Inoculated



White mustard (Sinapis albus)

Sphingomonas macrogoltabidus

Summary

- identified 16 cold-tolerant perennials as possible phytoremediator plants for field evaluation

Grasses

3 native grass

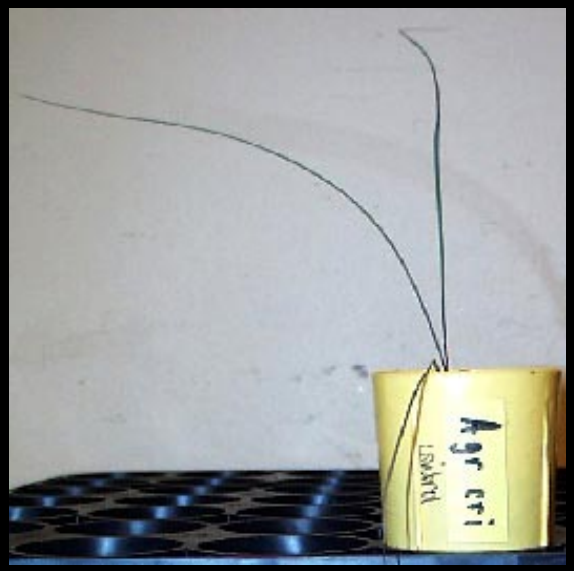
5 exotic grasses

Forbs

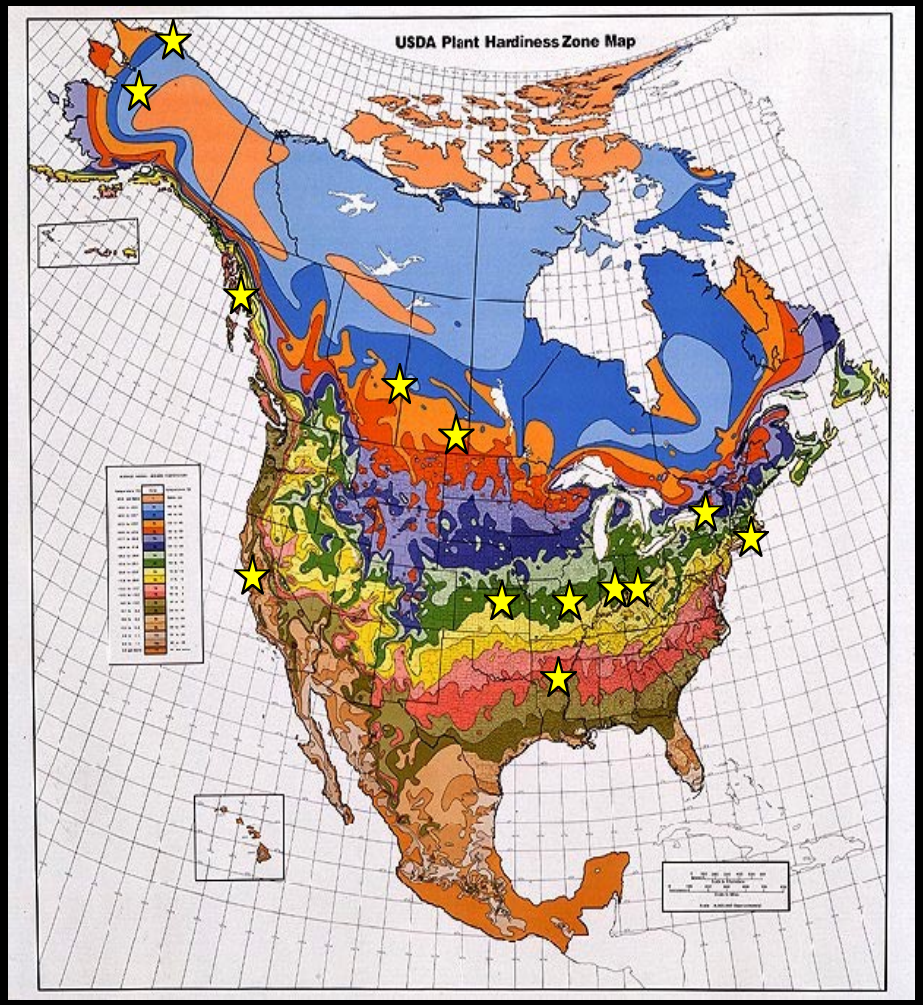
2 native legume

4 exotic legumes

2 native non-legumes



Field Studies (RTDF)



Standard experimental protocol

- (http://rtdf.org/public/phyto/protocol/protocol99.htm)
- RCBD with 4 treatments replicated 4 times
- 3 growing seasons (minimum)
- 2 sampling depths
- Analyzed for
  - TPH & TPH-fractions (CCME), PAHs, biomarkers
  - plant assessments
  - microbial diversity

Canadian RTDF Sites

Site L

- Boreal fringe
- East Central AB
- Black Chernozem to Gray Luvisol
- Sandy clay loam

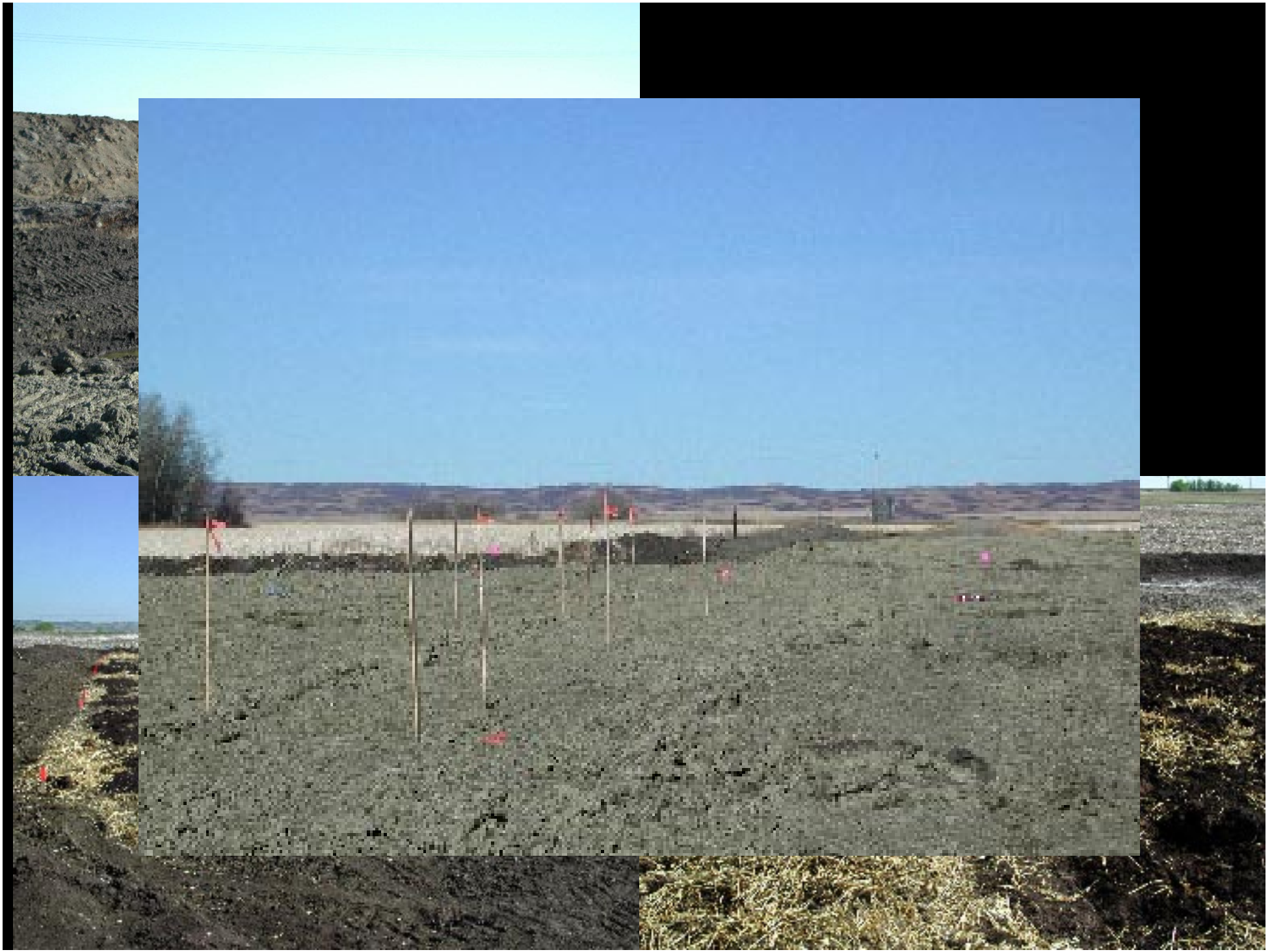
- Recently decommissioned flare pit
- ca. 1200 m^3
- ca. 16,000 ppm TPH

Site M

- Mixed grassland/parkland
- Southeast SK
- Dark Brown to Black Chernozem
- Heavy clay loam

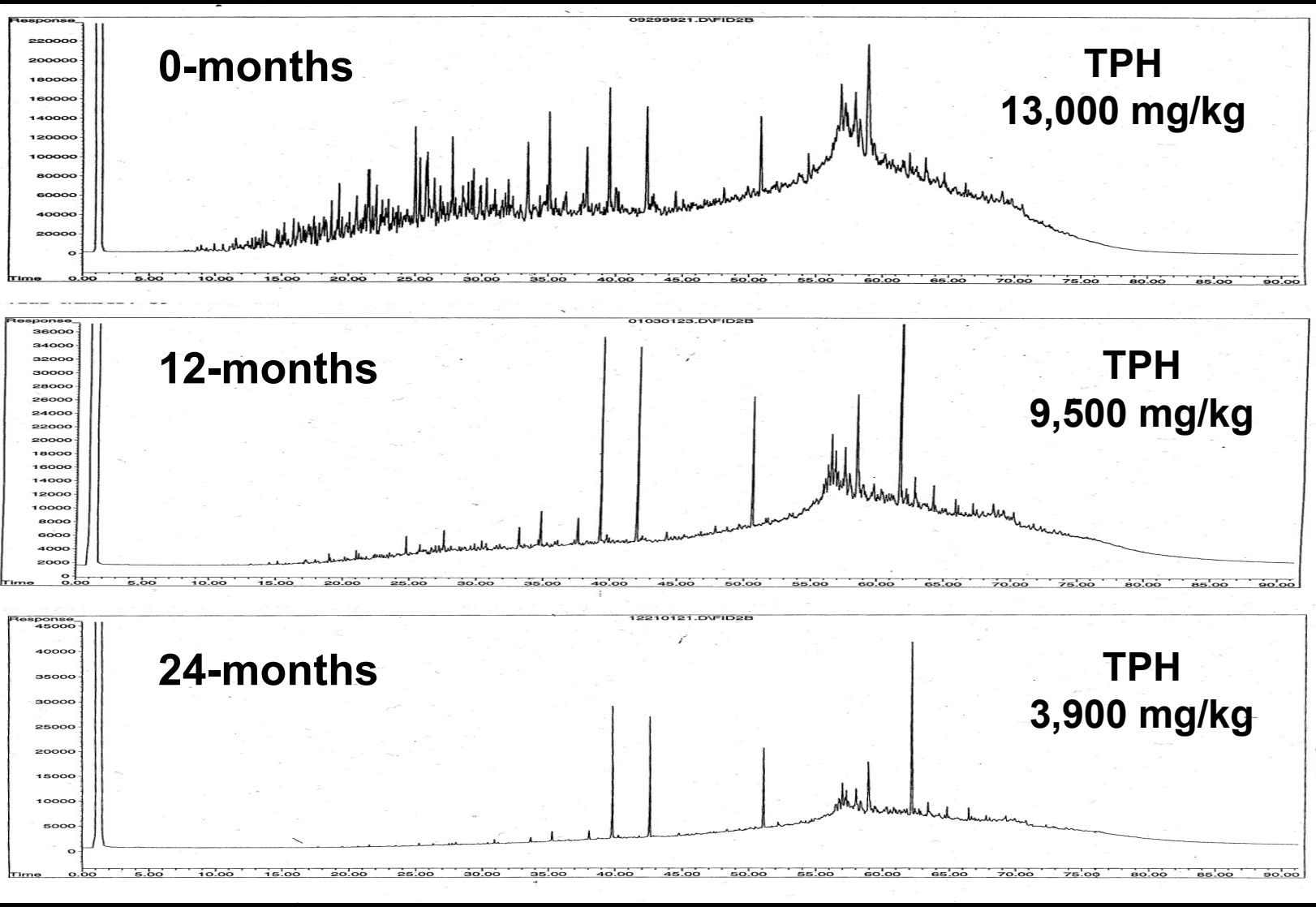
- Buried flare pit
- ca. 2400 m^3
- ca. 8,000 ppm TPH
- EC » 6 mS cm^{-1}

Site M




T1
T2
T4
T3

Total Petroleum Hydrocarbons (0 – 15 cm)



From the laboratory to the field:

Commercialization of Phytotechnologies

Advantages . . .

- Safety
  - minimize emissions & effluent resulting in low secondary waste volumes
  - controls erosion, runoff, infiltration, and dust emissions
- Ecological
  - habitat friendly, habitat creation, promotes biodiversity
  - sequester greenhouse gases (carbon dioxide)

Advantages . . .

- Public / Regulatory
  - acceptable brownfields applications
  - aesthetics, green technology
  - increasing regulatory approval and standardization
- Cost-Effective
  - multiple and mixed contaminants and media
  - low maintenance, passive, in situ, self regulating
  - solar-powered, energy efficient
  - remote operation, large areas

Limitations . . .

- Time
  - slower than some alternatives
  - climate dependent, seasonal
- Performance
  - not capable of 100% reduction in contaminant concentration
  - high concentration of contaminants may be toxic
  - plants may be difficult to establish at some sites
  - generally restricted to surface soils and relatively shallow aquifers or surface water
- Other
  - possibility (???) of contaminant transfer into the food chain
  - insufficient economic performance data to encourage wide-spread implementation

Commercialization potential

U.S. & International Phytoremediation Markets, 1999-2000
(D. Glass & Associates, 1999)

- Environmental remediation markets are governed by government regulation
- Canada is generally regarded as having “progressive” environmental policies
- Phytoremediation market in Canada is estimated at:

  $1.5-3M (1999) $2-3.8M (2002) $2.5-6M (2005)

- Market growth contingent upon strengthening of the regulatory framework and the enforcement efforts

Key market trends (1998–2000)

- Markets have nearly doubled in size, due to increased acceptance
- More consulting/engineering firms offer phytoremediation services
  - leading to greater competetion for jobs
- Most phytoremediation field work has been directed at organic and inorganic contaminants
  - The metals sector has been slower to develop
- Significant laboratory-, pilot-, and field-scale work is taking place in the U.S., Canada, and Europe

Future prospects

- Phytoremediation is an innovative technology with applications other than site remediation (e.g., wastewater treatment, landfill leachate control)
- Can be viewed as an extension of “natural attenuation”
- Inherent features that make phytotechnologies attractive include:
  - low cost
  - low energy requirements
  - low maintenance
  - compatability with risk-based remediation


Natural Sciences and Engineering Research Council (NSERC)
Saskatchewan Agriculture, Food & Rural Revitalization (SAFRR)
Environment Canada
Program for Energy Research & Development (PERD)
Canadian Association of Petroleum Producers (CAPP)
Talisman Energy
Husky Energy, Inc.
Federated Co-Operatives, Ltd. Imperial Oil Research
USEPA-RTDF