Practical Aspects of Phytoextraction: Six Years of Field Studies at Sites Historically Contaminated with Persistent Organic Pollutants (POPs)

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Phytoremediation defined:

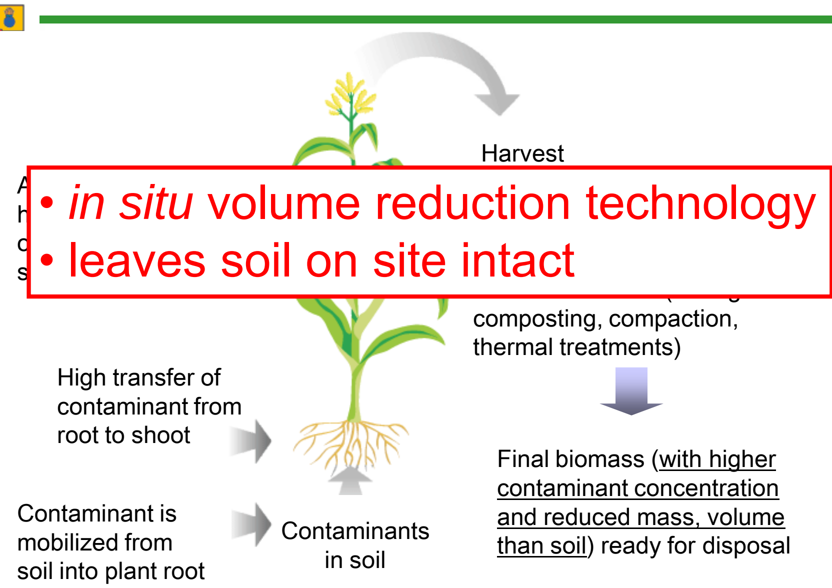
'a diverse group of green technologies that use either naturally occurring or genetically engineered plants to remove, reduce, degrade, or immobilize contaminants from soil, sediment, air or water'

- 1991 – term 'phytoremediation' coined
- 1999 – 1st issue of International Journal of Phytoremediation published

5 Broad Categories

Mechanism	Process Goal	Media	Typical Contaminants
Phytostabilization	Containment	Soils, sediments, sludges	As, Cd, Cr, Cu, Pb, Zn
Enhanced Rhizosphere Biodegradation	Remediation by destruction	Soils, sediments, sludges, groundwater	TPH, PAHs, BTEX, pesticides, chlorinated solvents, PCBs
Phytoextraction	Remediation by extraction and capture	Soils, sediments, sludges	Ag, Au, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Zn, Radionuclides
Phytodegradation	Remediation by destruction	Soils, sediments, sludges, ground and surface water	Organic compounds, chlorinated sovents, phenols, pesticides, numitions
Phytovolatilization	Remediation by extraction from media and release to air	Soils, sediments, sludges, groundwater	Chlorinated solvents, MTBE, Se, Hg, As

Phytoextraction



- *in situ* volume reduction technology
- leaves soil on site intact

Adapted from Nascimento and Xing, 2006

State of the Science

http://www.cluin.org/products/phyto/

US EPA – database summarizing known phytoremediation applications:

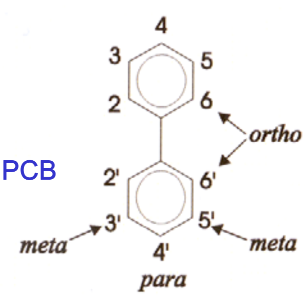
as of Dec 09 – 170 phyto projects included:

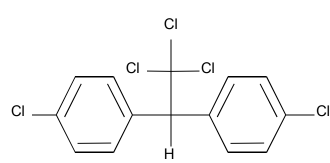
- 63 full-scale
  - 13 (21%) complete
- 101 demonstration-scale
  - 68 (67%) complete
- 6 large greenhouse-scale
  - 4 (67%) complete

<1% of all projects involved PCBs, DDTs, aldrin &/or dieldrin

Phytoextraction of POPs

PCB





DDT

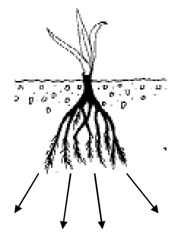
- some of most difficult molecules for plants to take up
  - low solubility in water (hydrophobic)

- despite being highly hydrophobic, CAN be taken up by some plants

Proposed Uptake Mechanisms

1. **Root exudates ↑ solubility of POPs?**
   - Roots produce molecules that interact with POPs & ↑ water solubility, thereby ↑ uptake & transfer

2. **Soil structure disruption?**
   - Organic acids cause partial dissolution of soil matrix, thereby releasing bound pollutants



Adapted from Dakora and Phillips, 2002

Advantages

- **Safety**
  - Minimized emissions & effluent, low secondary waste volume
  - Control erosion, runoff, rain infiltration & dust emissions
- **Ecological**
  - Habitat creation, promotes biodiversity
  - Sequesters greenhouse gases (CO_2)
- **Public / Regulatory**
  - Acceptable brownfields applications
  - Aesthetics, green technology
  - Increasing regulatory approval & standardization
- **Cost-Effective**
  - Multiple & mixed contaminants & media
  - Low maintenance, passive, *in situ*, self-regulating
  - Solar-powered, energy efficient
  - Remote operation, large areas

Limitations

- **Depth**
  - Only effective within relative rooting depth of vegetation
- **Time**
  - Requires longer periods to become effective (establishment) and to reach clean-up targets
  - Seasonal effects
- **Phytotoxicity**
  - applicable for low - moderate contaminant concentrations
  - In most cases, vegetation must survive in order to be effective
- **Media Transfer / Food Chain Impacts**
  - Fate and transport often unclear
  - Air emissions, leaf litter
  - Harvesting, hazardous waste?

Recent Advancements in POPs Phytoextraction

1. Plant performance over repeated field seasons
2. Enhancement of POPs phytoextraction by the addition of soil amendments
3. Simple agricultural practices to increase plant biomass
4. Potential use of native plant species for effective POPs phytoextraction
5. On-site treatment of POPs-contaminated plant waste

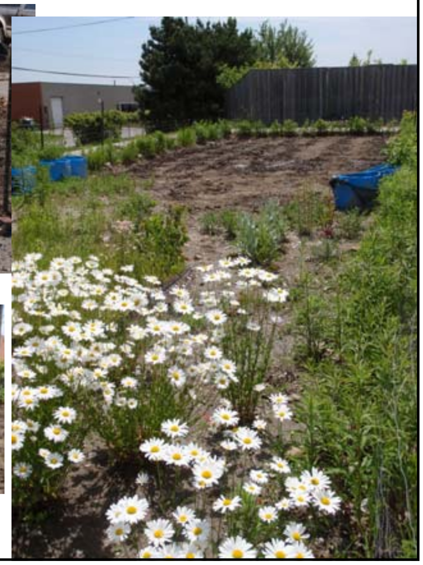
Field Sites

Site #1 - Etobicoke, ON

former transformer manufacturing facility

Aroclors 1254 & 1260

$[PCB]_{soil}$ = ~30 μg/g



Site #2 - Lindsay, ON

former industrial chemical plant

Aroclor 1248

$[PCB]_{soil}$ = ~4.7 μg/g

Cucurbita pepo ssp. *pepo* var. Howden (pumpkin)

The awakening colossus: The reality of 'one China'. Page A14

NATIONAL POST

In gourd we trust: Pumpkins hailed as pollution fighters

CLEANING UP CONTAMINATED SOIL

By Tom Spears

OTTAWA – Ordinary pumpkins and zucchini can do what few other plants can – suck DDT, PCBs and probably other pollutants out of contaminated soils.

Scientists from Royal Military College in Kingston, Ont., have just published this discovery, in which they lowered DDT levels in soil from a site where DDT "fogging" was once a regular event to kill mosquitoes.

… tive than digging up all the tainted soil and incinerating it, they say.

Just don't eat the pumpkins afterwards.

Using plants to soak up pollution is a new trend in favour with the U.S. Environmental Protection Agency.

But DDT and PCBs are widespread pollutants that present one big problem: they don't bind easily to water. And this makes it nearly impossible to wash them out of soil, or to use most plants to absorb them. But at RMC, chemists Ken Reimer and Barbara Zeeb learned that a few plants do soak up these pollutants. They put them in a pumpkin shell, and there they keep them very well.

… niche," Mr. Reimer said yesterday. "You're using the plant as a straw to suck the contamination out of the ground."

A badly contaminated site that needs a fast cleanup will still demand excavation and incineration of the soil, but this destroys the soil. It's literally a scorched earth practise.

"I think there's a real niche here for low-level contamination, or maybe where a developer is looking to improve the environmental quality of the land over a period of time using a less-expensive and less-intrusive technology," he said. "And pumpkins just happen to be a family of plants that are good at picking up these …

It's a lot easier to haul away tainted pumpkins than to haul off an entire tainted field of soil. Composting the pumpkin plants first reduces the volume.

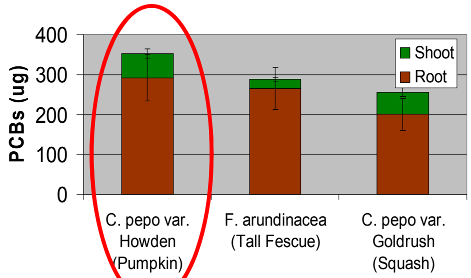
Pumpkins are twice as good as zucchini at sucking up DDT, he says. One advantage they have is sheer size. As with sponges and paper towels, a big squash will soak up more than a small one. But there are also sedges – wild grasses – that work well, possibly better than pumpkins. They have the advantage of growing all season long.

The Reimer-Zeeb team is publishing its results in Environmental Science & Technology, a journal of the American Chemical Society. They're continuing their work, investigating "surfactants" – soap-like chemicals that might loosen the soil's grip on pollutants and allow plants to soak them up better.

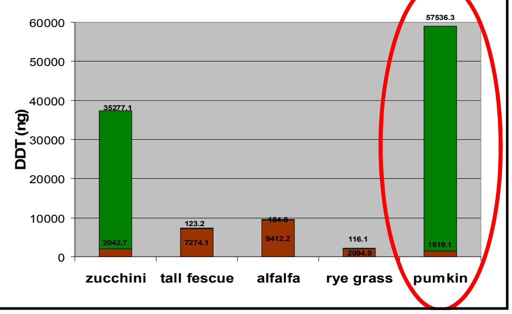
DDT and PCBs were both banned in the 1970s in the United States and Canada, but are still used in Central America and elsewhere. They last for decades in soil.

CanWest News Service

PCB vs. DDT Phytoextraction

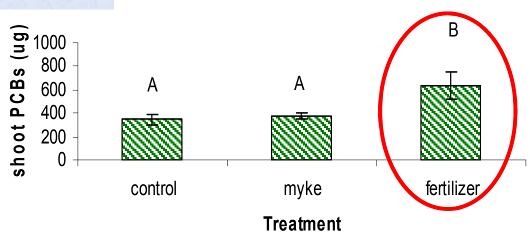


1. Lunney, A. Zeeb, B.A., and Reimer, K. J. 2004. **Uptake of weathered DDT in vascular plants**: potential for phytoremediation. Envt. Sci. Tech. 38: 6147-6154.
2. Whitfield Aslund, M., Lunney, A., Rutter, A., and Zeeb, B.A. 2010. **Effects of amendments on the uptake and distribution of DDT** in *Cucurbita pepo* ssp *pepo* plants. Environ. Poll. 158: 508-513.
3. Lunney, A., Rutter A., and Zeeb, B.A. **Effect of organic matter additions on uptake of weathered DDT** in *Cucurbita pepo* ssp *pepo* cv. Howden. Int. J. Phytoremediation (in press).



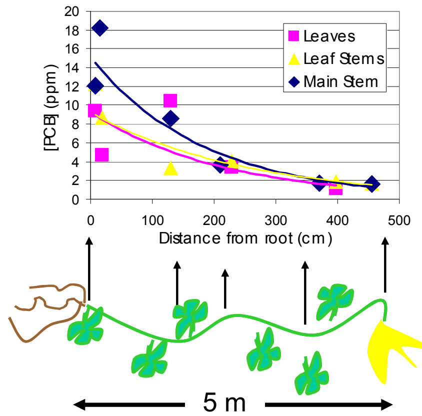
2. Soil Amendments to Increase Plant Biomass

- Numerous amendments tried over the years in greenhouse & field including:
  - various surfactants
  - fertilizers
  - mycorrhizal fungi
  - root exudates



3. Agricultural Practices to Increase Plant Biomass

1. **Pruning**
   – to ↑ biomass of plant near base to maximize PCB uptake
2. **Encouraging Nodal Roots**
   – to ↑ # of PCB uptake pathways



Whitfield Åslund, M., Zeeb, B.A., Rutter, A., and Reimer, K.J. 2007. *In situ* phytoextraction of polychlorinated biphenyls (PCBs) from weathered, PCB-contaminated soil. Sci. Tot. Envt. 374: 1-12.

4. Use of Native Plant Species for PCB phytoextraction

- 27 species of free-growing weeds harvested in triplicate from 2 field sites
- $[PCB]_{\text{weed shoot}}$ compared to $[PCB]_{\text{pumpkin shoot}}$

Ox-Eye Daisy

Scotch Thistle

Goldenrod

Density Effects

to compare plant extraction efficiencies, determine amount of PCB extracted per unit area of soil; – this will vary based on optimal plant density

- e.g. *Cucurbita pepo* grows optimally at 1 plant per m^2

6. On-site Treatment of PCB-Contaminated Plant Waste

- How much volume reduction can be achieved?

Compost Over 1 Field Season

April 24th

April 24th

May 28th

June 5th

June 12th

June 19th

June 26th

July 3rd

Summary

1. PCB phytoextraction appears to be constant over time

2. Use of fertilizer and simple cultivation techniques can be used to create larger plants & phytoextract more PCBs

3. Many weed species have potential to extract ≥ quantities of PCBs than *C. pepo* per m^2

4. Composting is effective means of significantly reducing plant biomass prior to disposal

Conclusions

- new work shows phytoextraction to be viable remediation technology for some POPs- contaminated soils
  - slow, but effective
  - useful in areas with limited resources
  - most applicable for large areas with low level contamination
  - leaves soil matrix intact
  - less expensive than traditional remediation technologies

Questions

Natural Sciences and Engineering Research Council of Canada

Conseil de recherches en sciences naturelles et en génie du Canada

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Jacques Whitford