PAH Phytodegradation & Habitat Restoration at a Historic Industrial Coke Oven Facility

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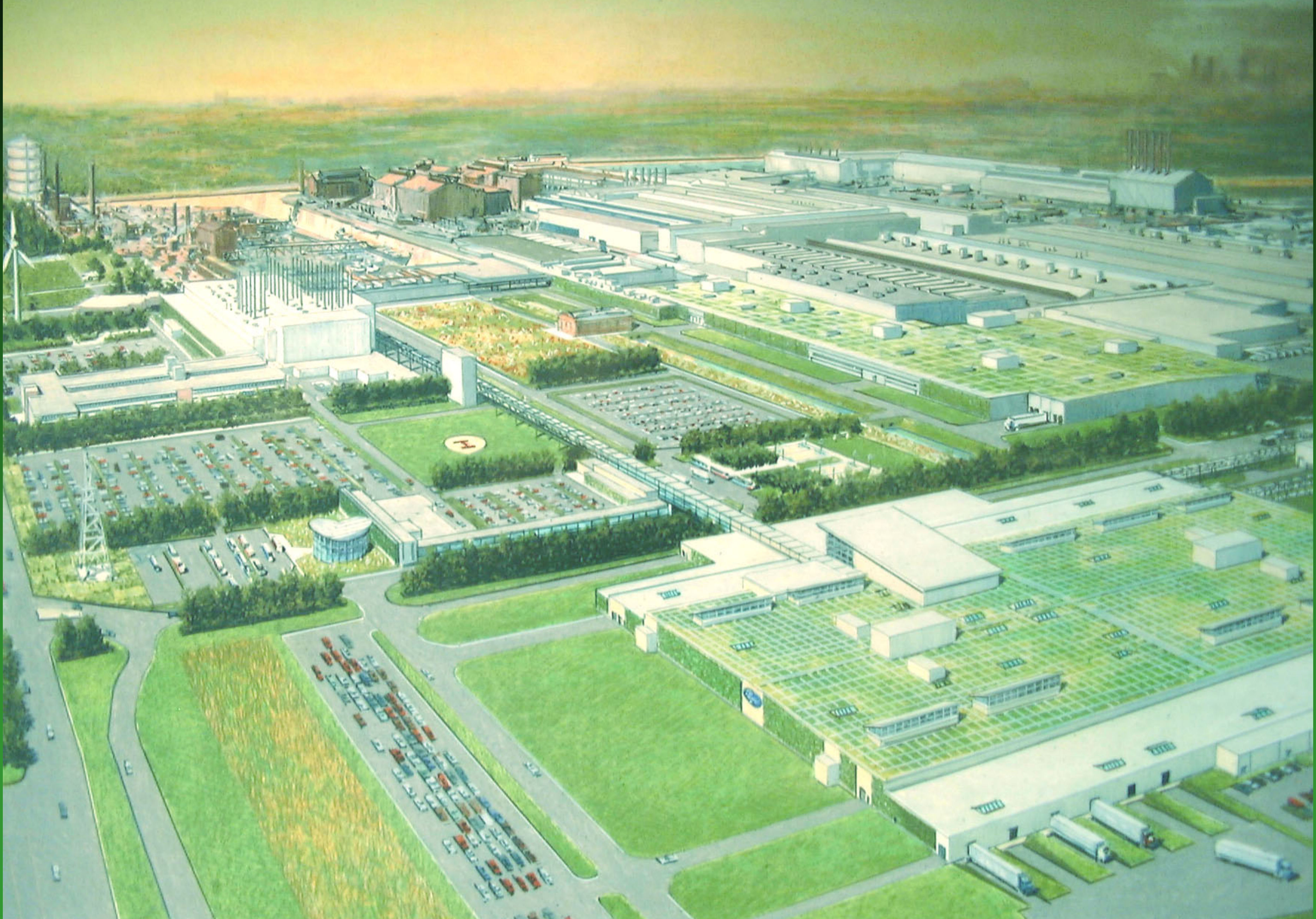
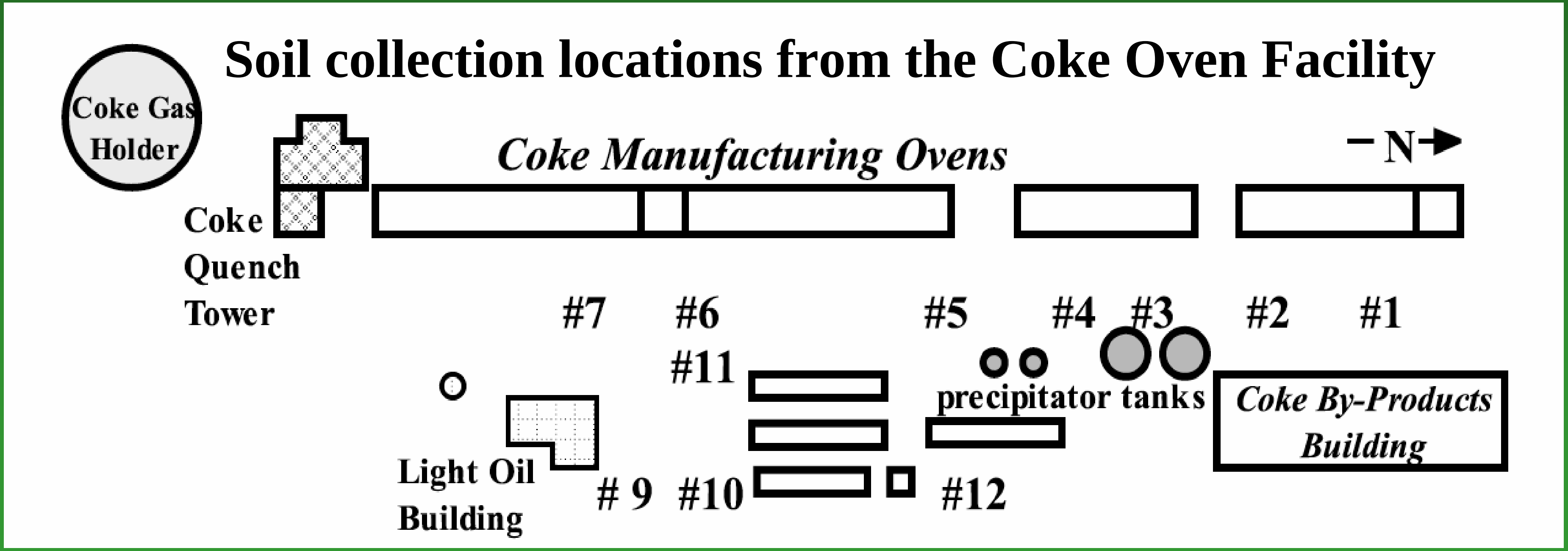
Univ of Michigan-Dearborn

Rouge Manufacturing Complex (Dearborn, MI)

Rouge Heritage Project – conceptualized by McDonough +Partners

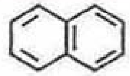


Rouge Manufacturing Complex – Coke Oven Area

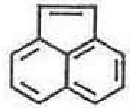


Polyaromatic Hydrocarbon (PAH) Chemical Structures

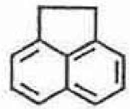
Naphthalene



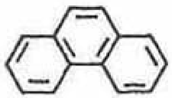
Acenaphthene



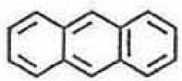
Acenaphthylene



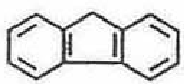
Phenanthrene



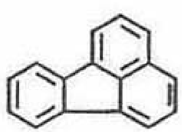
Anthracene



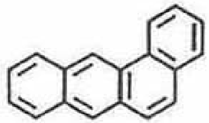
Fluorene



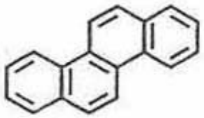
Fluoranthene



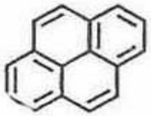
Benz(a)anthracene



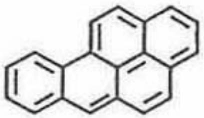
Chrysene



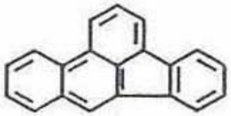
Pyrene



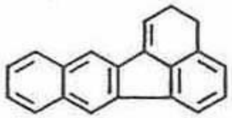
Benzo(a)pyrene



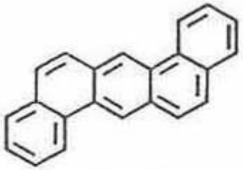
Benzo(b)fluoranthene



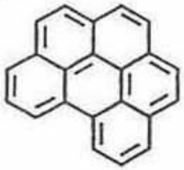
Benzo(k)fluoranthene



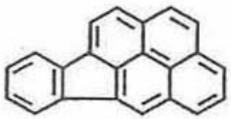
Dibenz(a,h)anthracene



Benzo(ghi)perylene



Indeno(1,2,3-cd)pyrene



Ecological or Intrinsic Phytoremediation

- Use of managed, natural systems
- Emphasis on sustainability
  - Regional native species + composts

Plant-Enhanced PAH Biodegradation

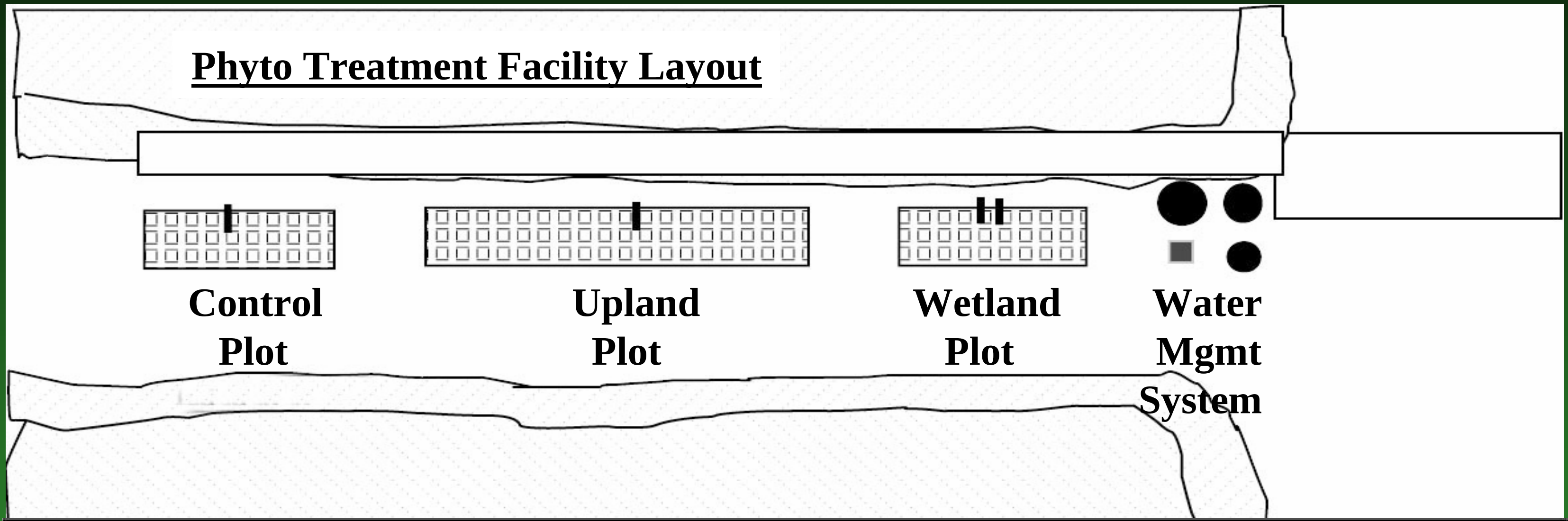
- *Rhizostimulation* of bacterial dioxygenase activity
- Root exudates as nutrients and co-metabolites

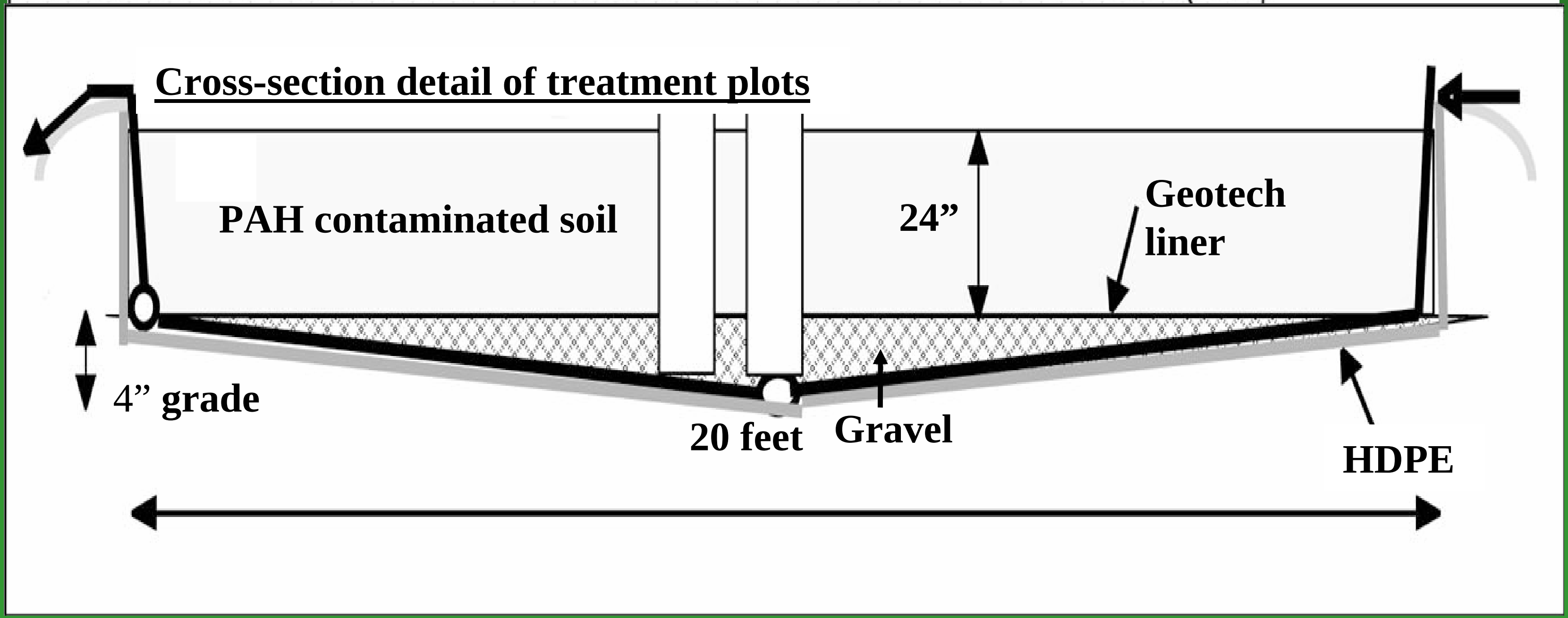
Phyto Field Trial - Selected Upland Plant Species

	Scientific Name	Common Name
Grasses	*Andropogon gerardii*	Big Bluestem
	Andropogon scoparius	Little Bluestem
	Hystrix patula	Bottlebrush Grass
	Spartina pectinata	Prairie Cordgrass
Sedges	*Carex sprengelii*	Sprengel Sedge
	Scirpus atrovirens	Bulrush
Herbaceous	*Amorpha canescens*	Leadplant
	Aster novae-angliae	New England Aster
	Cirsium discolor	Pasture Thistle
	Eupatorium perfoliatum	Boneset
	Eupatorium purpureum	Joe-Pye Weed
	Geum triflorum	Prairie Smoke
	Lobelia cardinalis	Cardinal Flower
	Silphium teribinthinaceum	Prairie-dock
Shrubs	*Ceanothus americanus*	New Jersey Tea
	Physocarpus opulifolius	Common Ninebark
	Spirea alba	Meadowsweet
	Viburnum dentatum	Arrowhead Viburnum

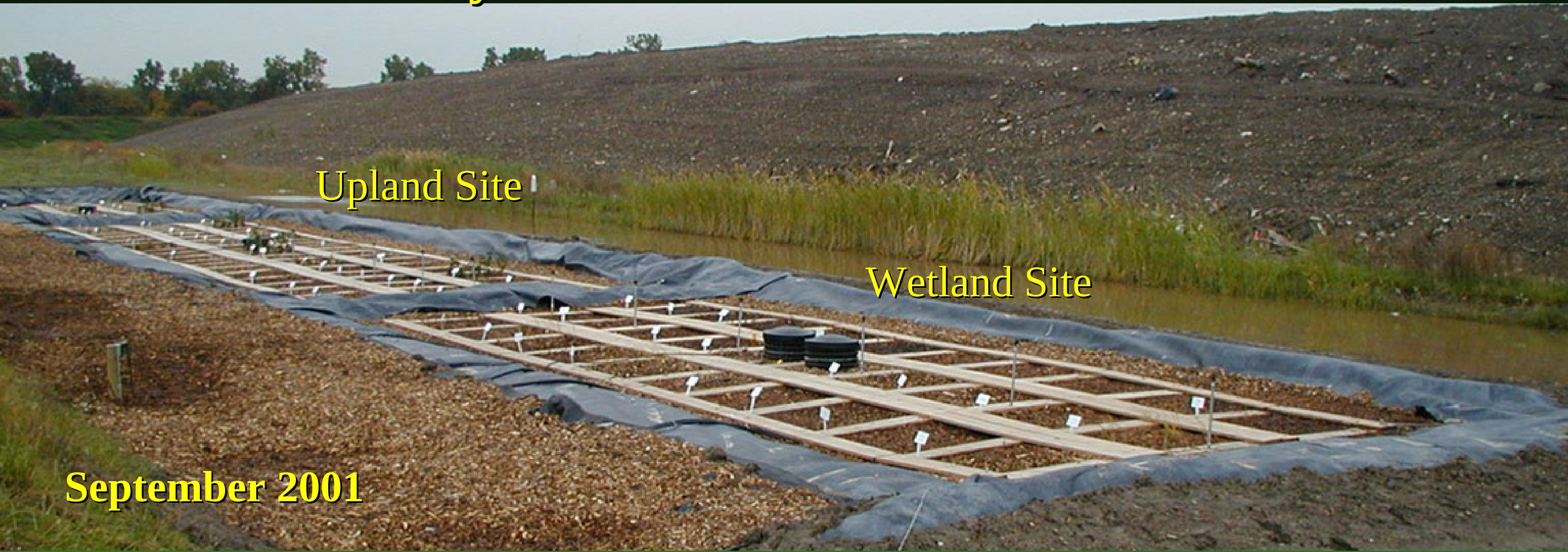
Phytoremediation Demonstration Plots

Constructed at Allen Park Clay Mine Landfill by URS Corp.

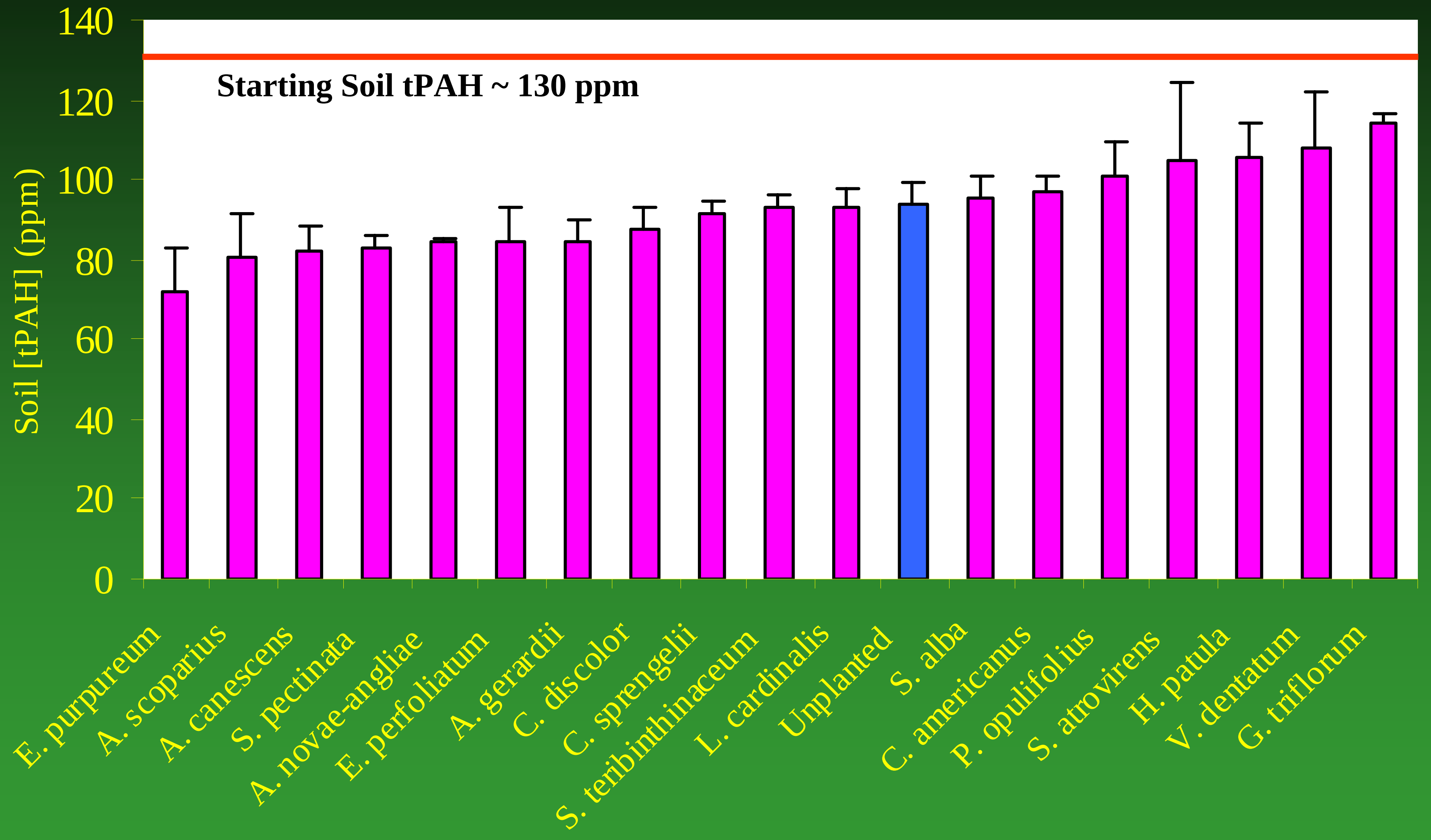




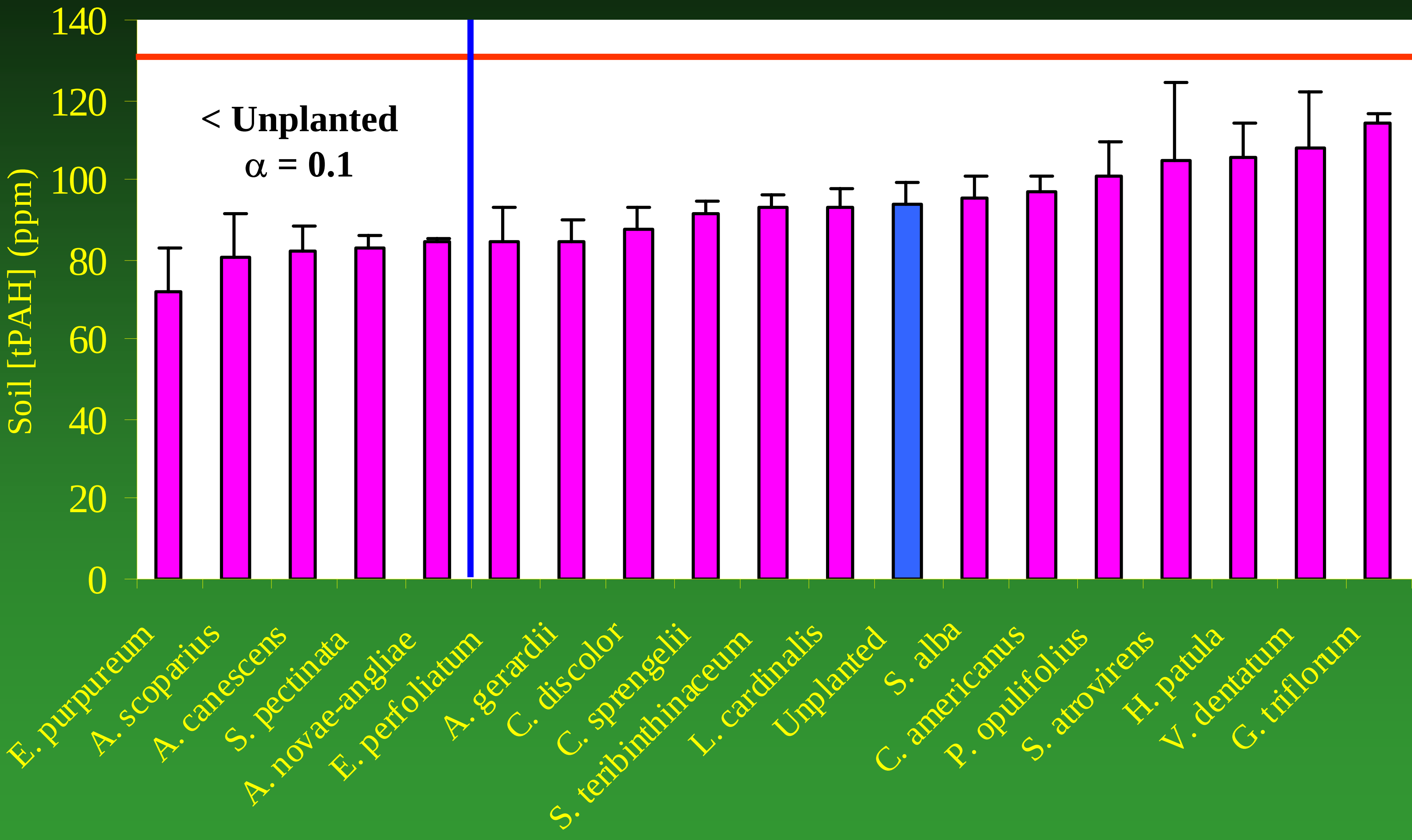
Ford Phytoremediation Field Trial Plots



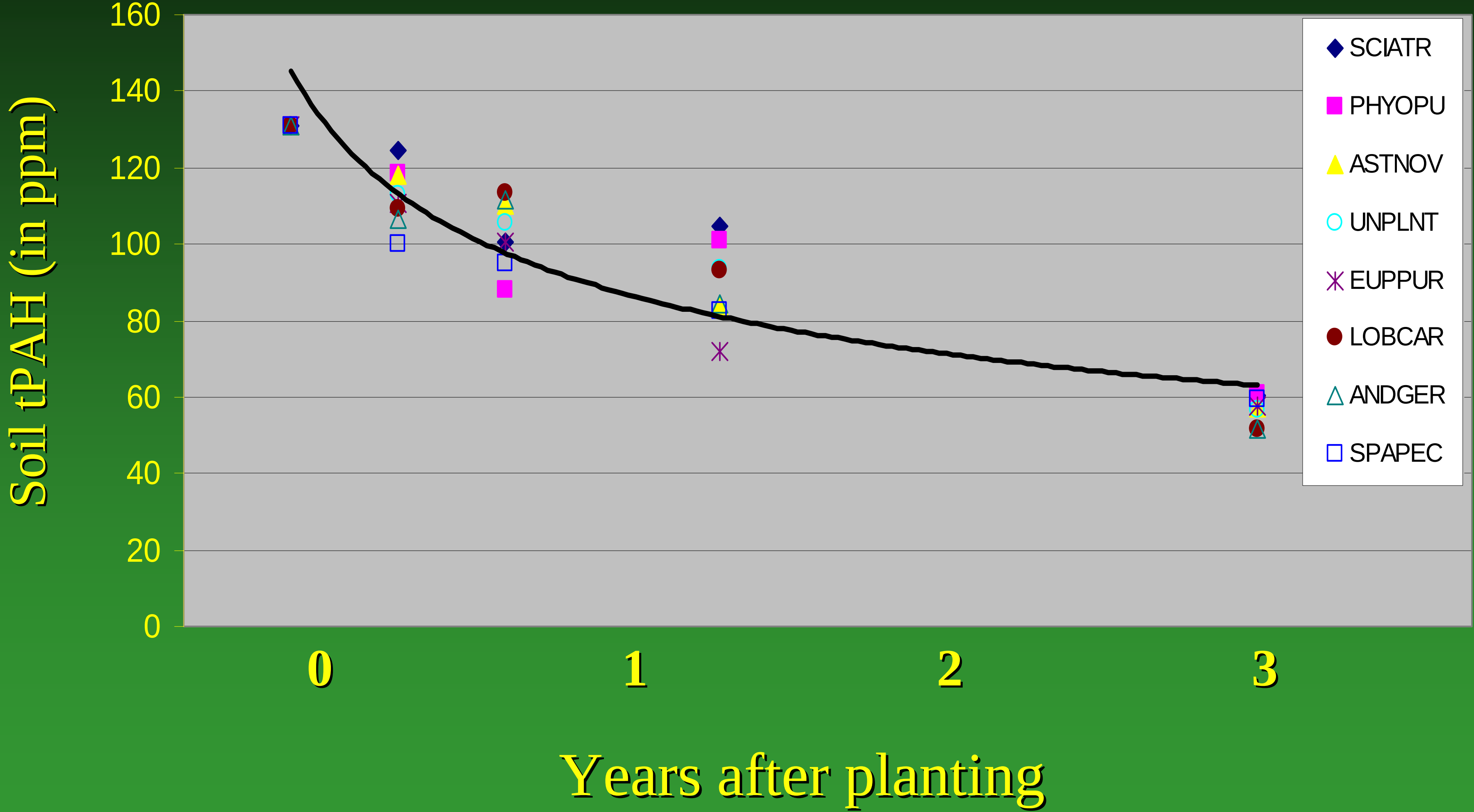
Upland Plot Soil [tPAH] - Sept 2001 (Yr 1)



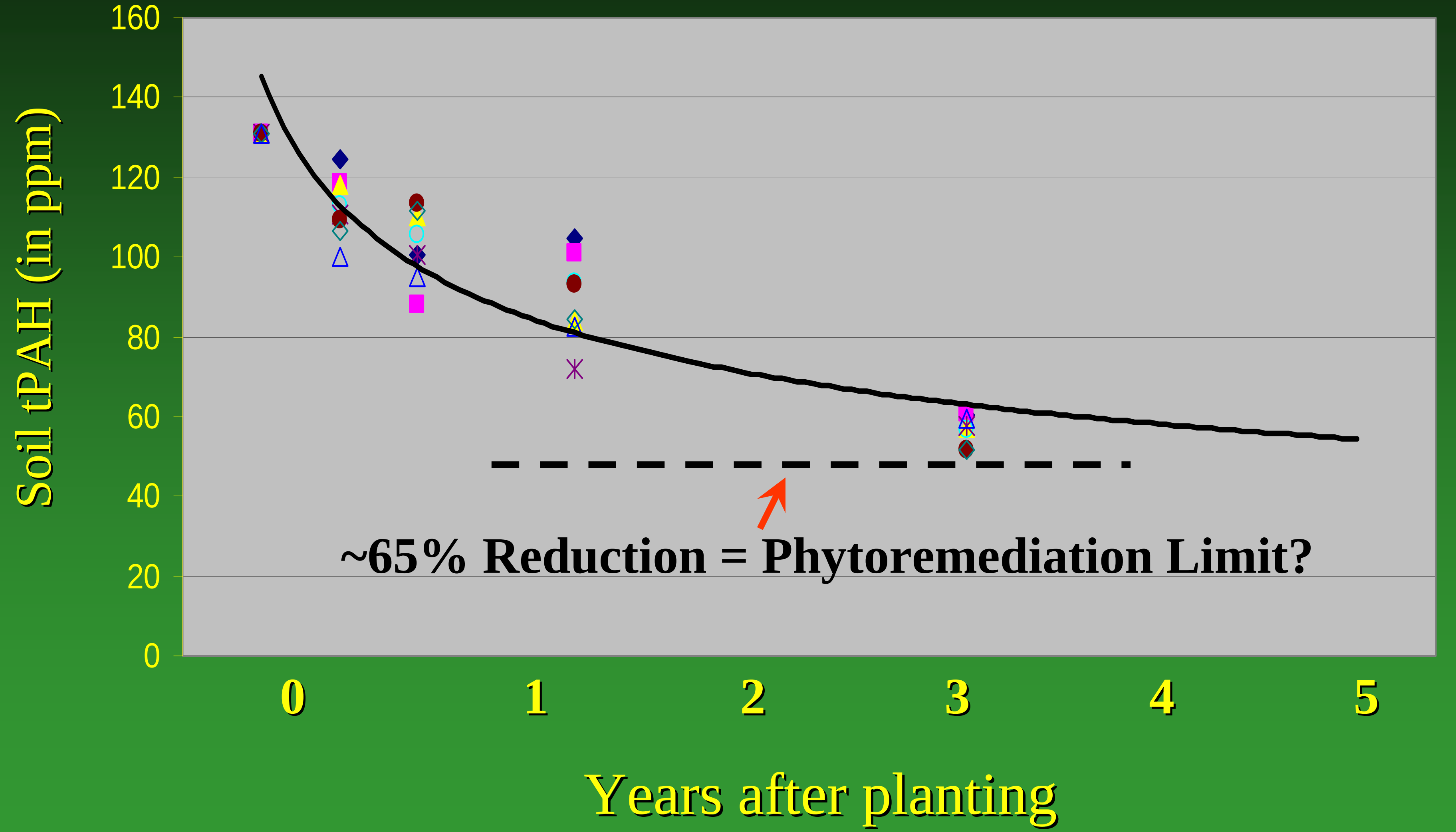
Upland Plot Soil [tPAH] - Sept 2001 (Yr 1)



Final Soil tPAH Concentration for Selected Treatments



Projected Soil tPAH Concentration for Phyto Treatments



Solubility Properties of Selected POPs

PCBs	log(Kow)		PAHs	log(Kow)
Biphenyl	4.1		Benzene (C_6H_6)	2.1
2-CBP (1 Cl)	4.5		Naphthalene ($C_{10}H_8$)	3.4
4-CBP (1 Cl)	4.4		Phenanthrene ($C_{14}H_{10}$)	4.5
4,4'-CBP (2 Cl)	5.2		Anthracene ($C_{14}H_{10}$)	4.5
2,4,5-CBP (3 Cl)	5.7		Chrysene ($C_{18}H_{22}$)	5.6
2,3,'4,4'-CBP (4 Cl)	6.3		Benzo(a)pyrene ($C_{20}H_{12}$)	6.5
Decachloro-BP (10 Cl)	8.2		Benzo(g,h,i)perylene ($C_{22}H_{12}$)	7.2

Hydrophobicity is measured as solubility in Octanol divided by Aqueous Solubility

Ex. Phenanthrene has a log K_{ow} = 4.46

…which equals 28840.32X more Phen in octanol phase than in aqueous

Particle-Scale Understanding of the Bioavailability of PAHs in Sediment. Talley, Ghosh, Tucker, Furey, Luthy. 2002. ES&T 36:477-483

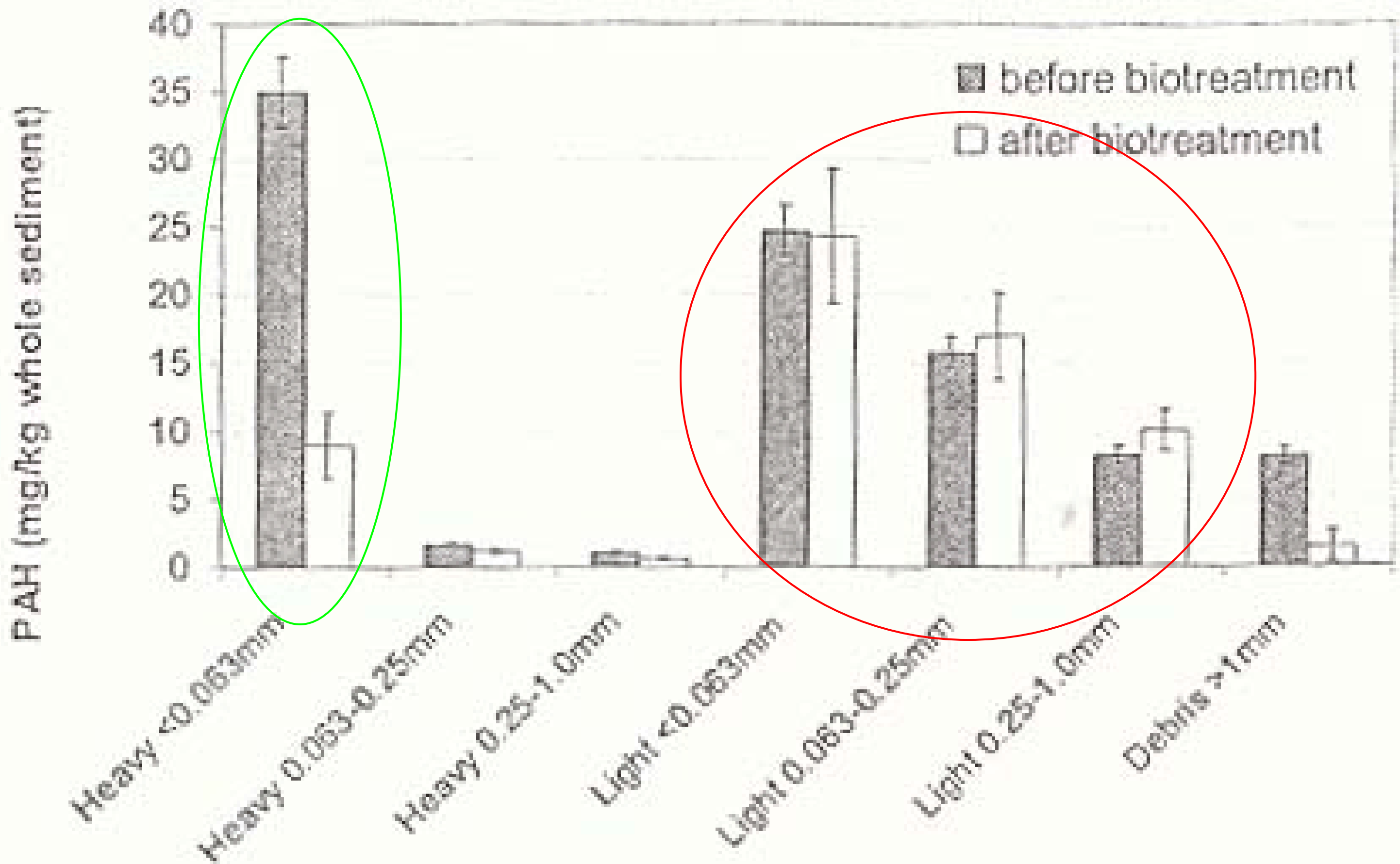
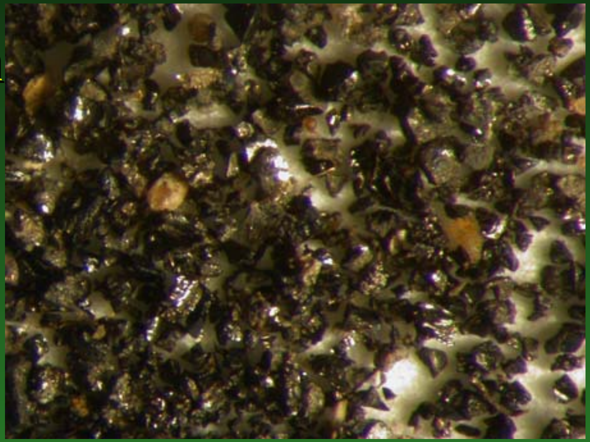


FIGURE 3. PAH reduction in sediment fractions before and after bioslurry treatment. These values are based on the contribution of each fraction to the total PAH concentration of 90 mg/kg as measured by GC-FID. Error bars indicate ± 1 SD based on analysis of four reactors.

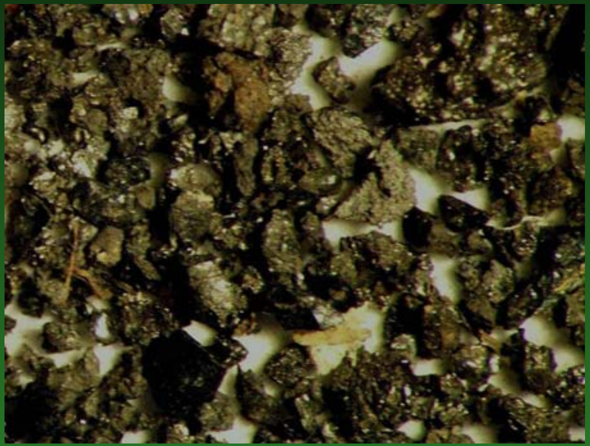
Particle Fractionation of Rouge Soil (Luthy lab, Stanford Univ.)

Size Separation @ 250μ & Density Separation @ 1.8 g/ml (sat'd CsCl)

Soil Organic Fraction
21% w/w

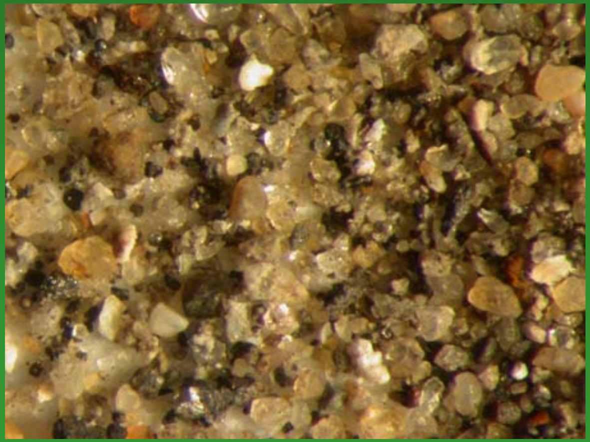


Light Soil (63-250 μ)



Light Soil (250-1000 μ)

Soil Mineral Fraction
79% w/w



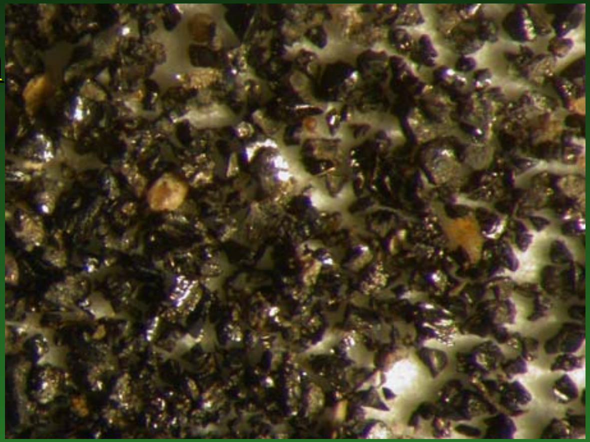
Heavy Soil (63-250 μ)

Heavy Soil (250-1000 μ)

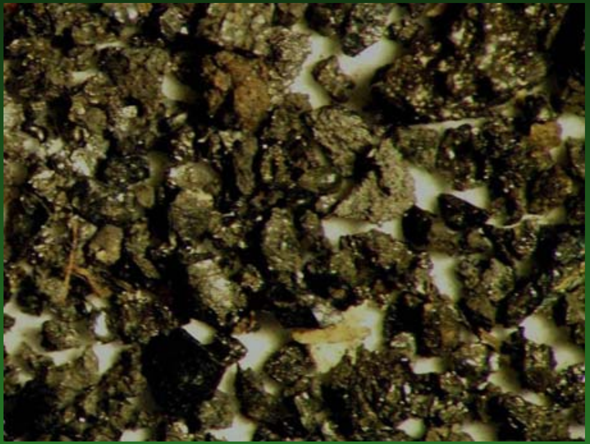
Particle Fractionation of Rouge Soil (Luthy lab, Stanford Univ.)

Size Separation @ 250μ & Density Separation @ 1.8 g/ml (sat'd CsCl)

Soil Organic Fraction
21% w/w
75% tPAH content

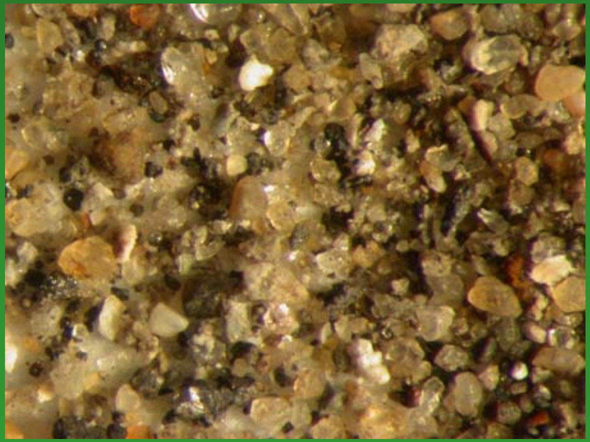


Light Soil (63-250 μ)



Light Soil (250-1000 μ)

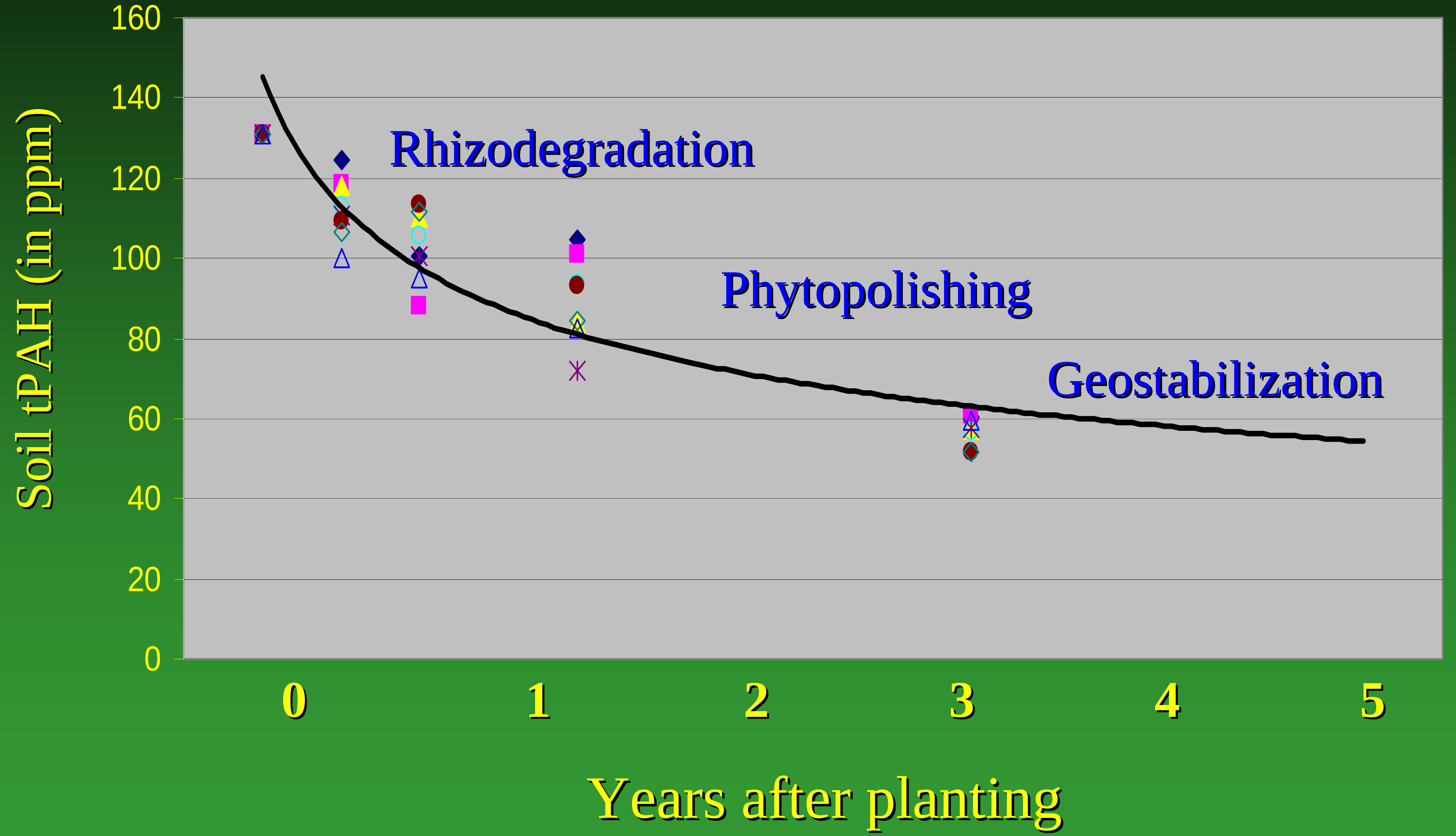
Soil Mineral Fraction
79% w/w
25% tPAH content



Heavy Soil (63-250 μ)

Heavy Soil (250-1000 μ)

Progressive Mechanism of Soil Phyto Treatments



Part II. Rhizosphere Ecology Influences

- **Root Quantification and Density**

  Excavation and isolation of root biomass

  What is a “rhizosphere”?

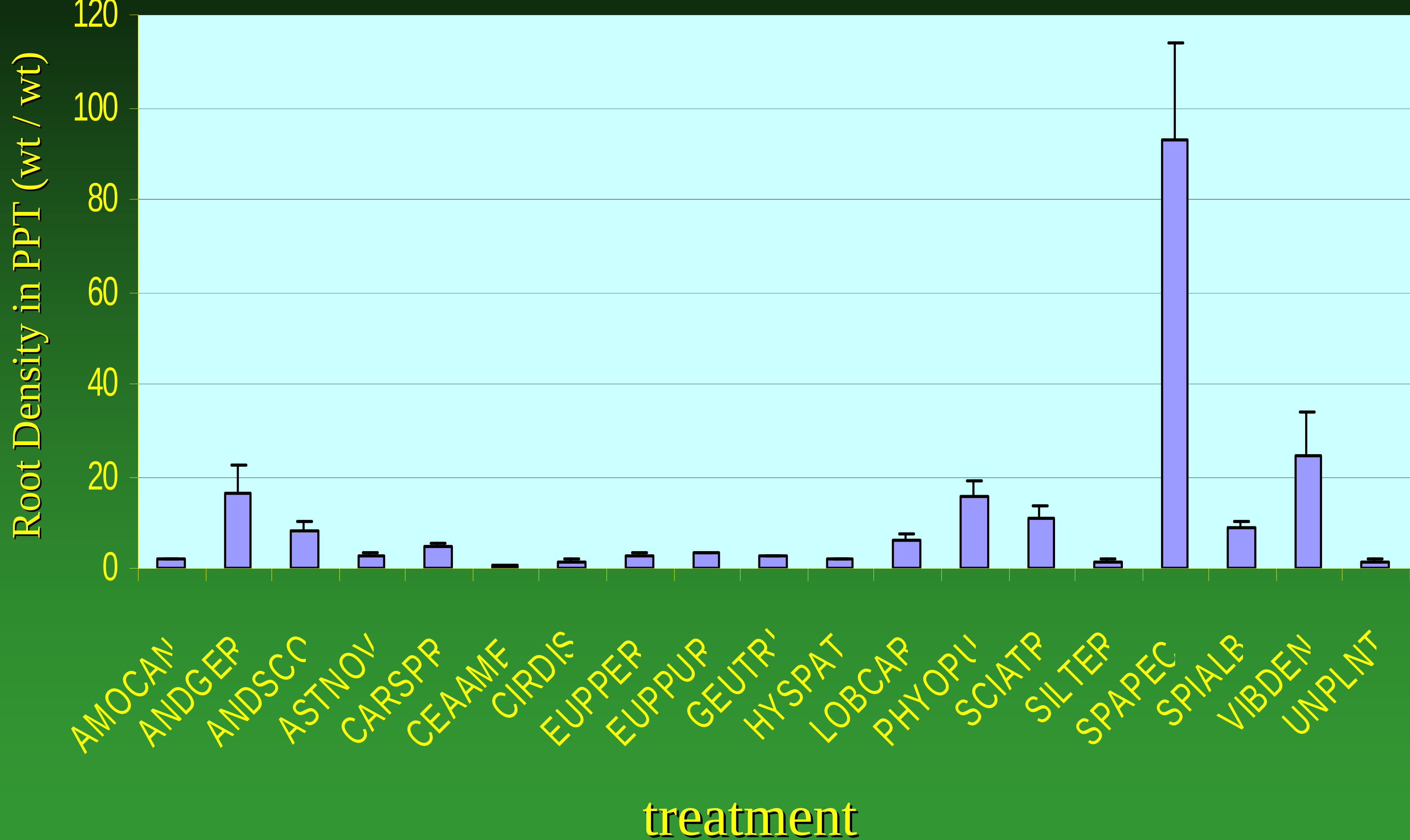
- **“The area of the soil influenced by root systems…”**

  - estimated to be as much as 3% of soil volume

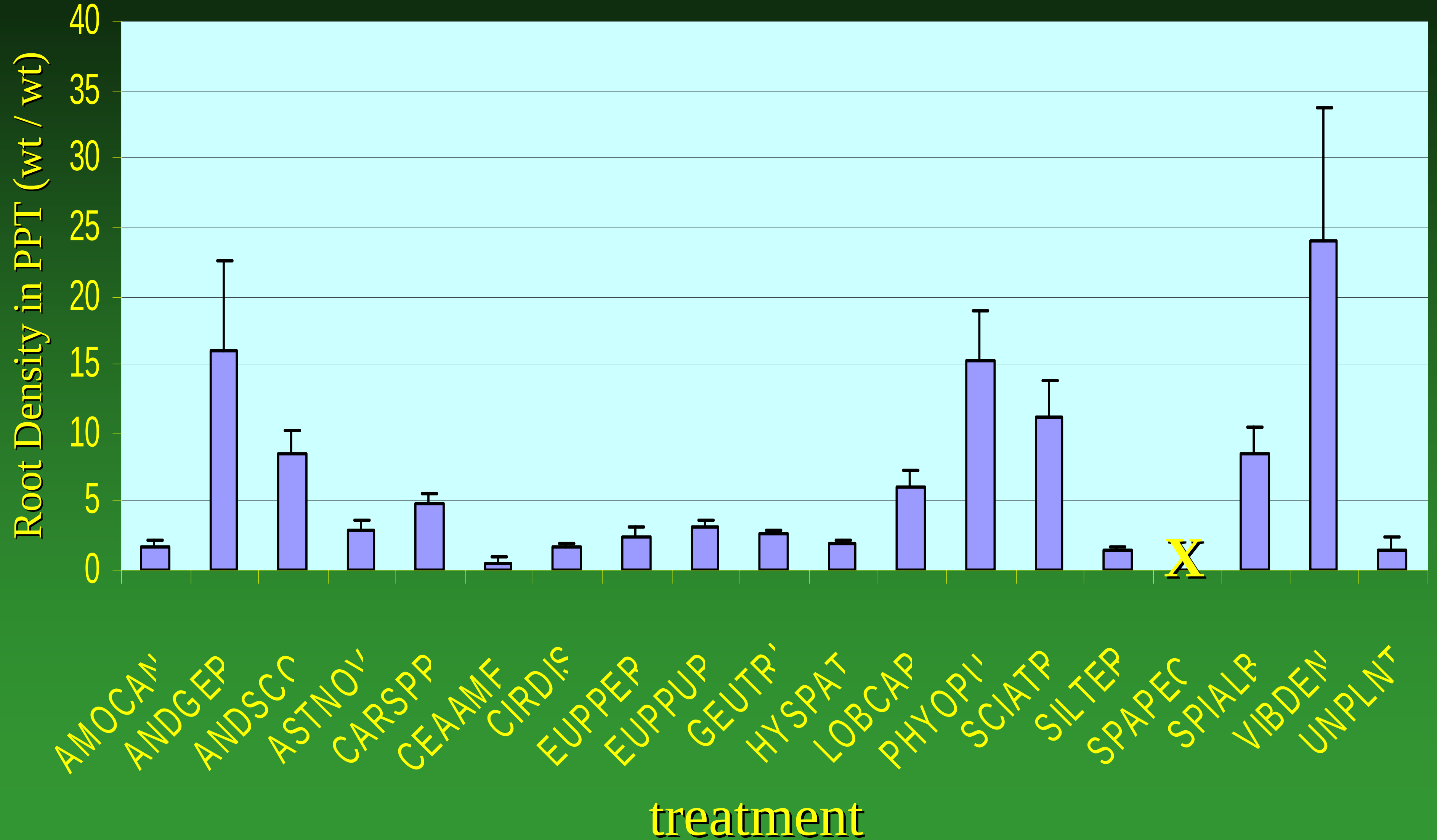
  (J. Fletcher, Univ. of Oklahoma)

  - soil that “stays attached to roots after shaking”

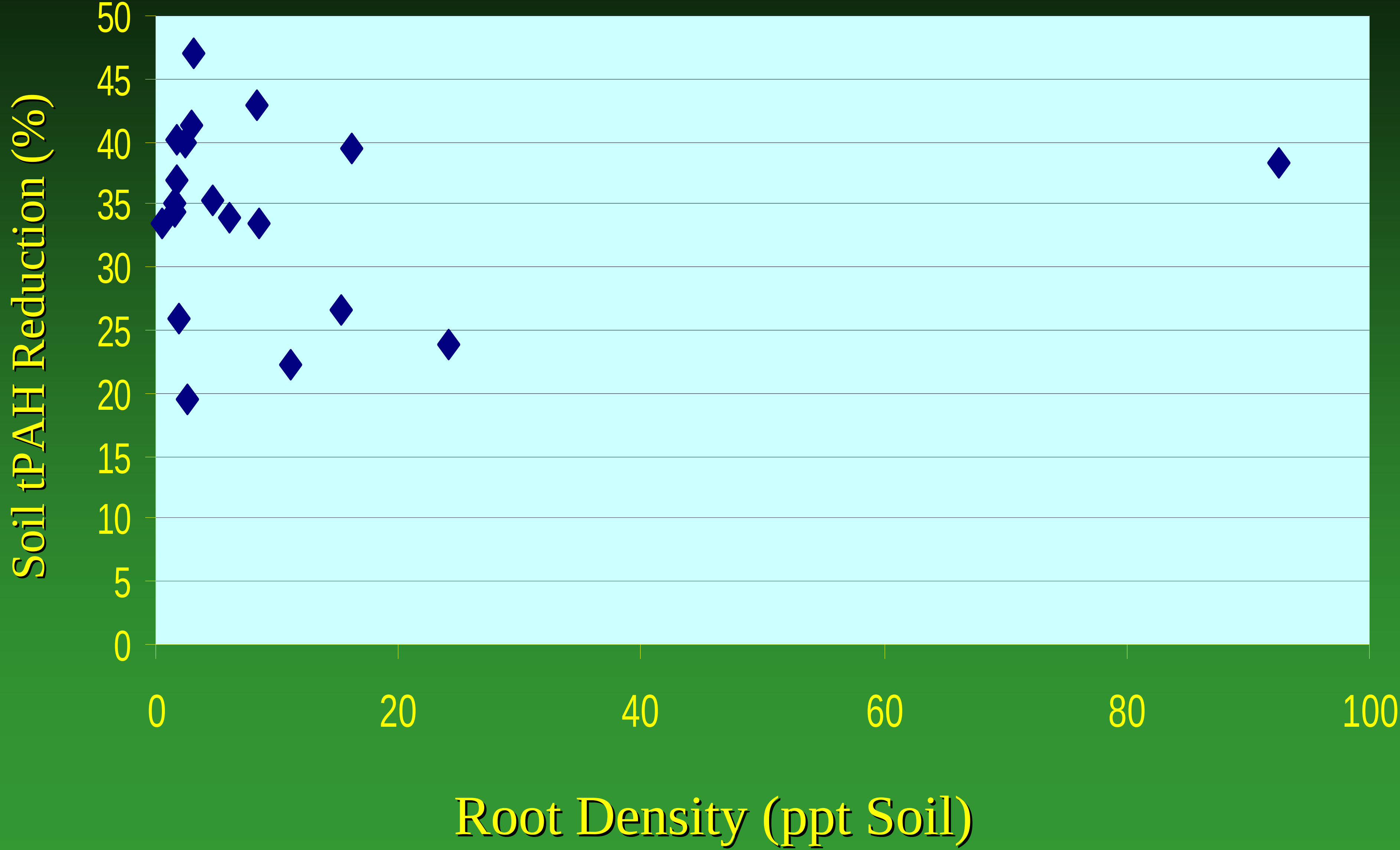
Root Biomass Density relative to Soil (cu. yd.)



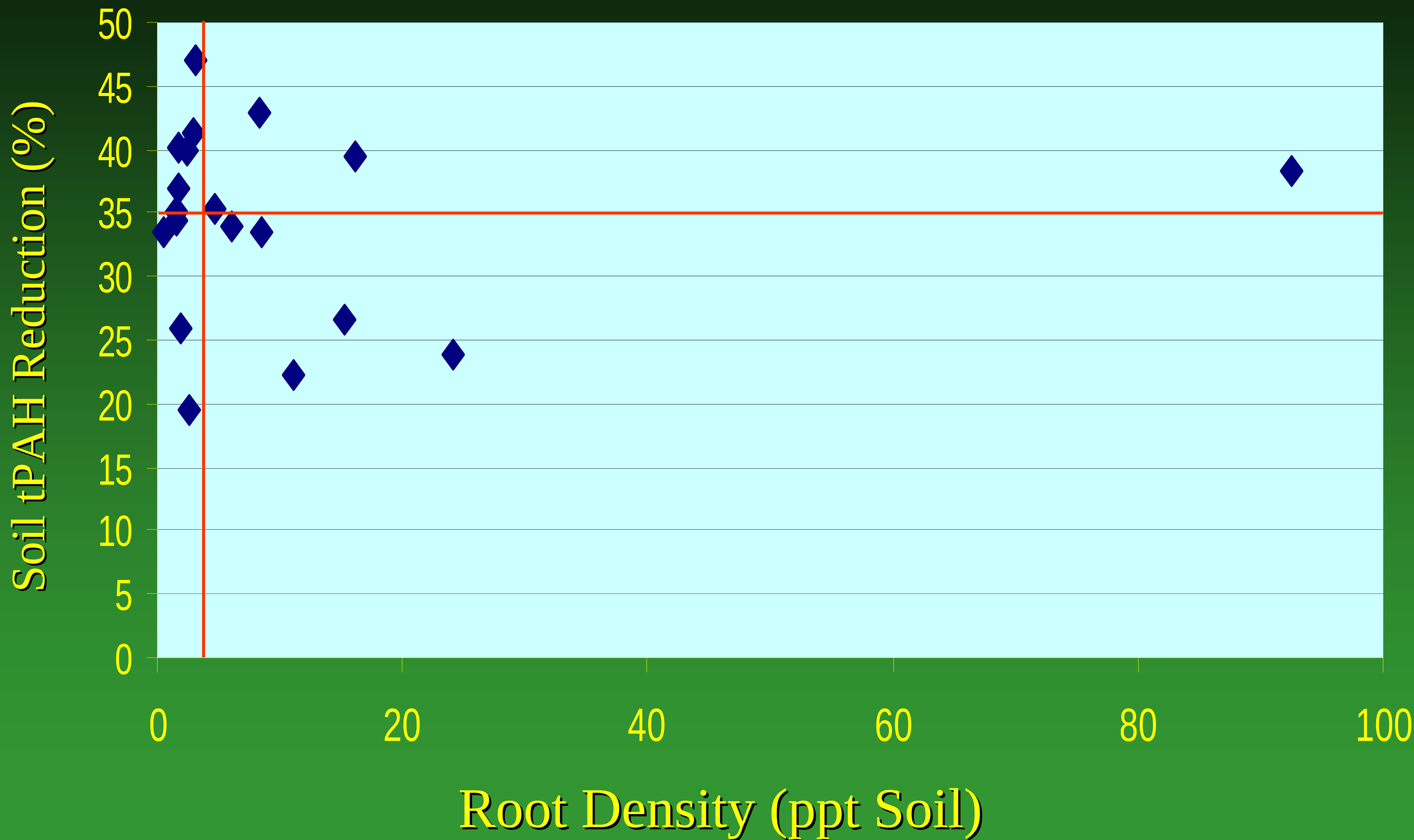
Root Biomass Density relative to Soil (cu. yd.)



Root Biomass Influence on PAH Reduction



Root Biomass Influence on PAH Reduction



Root-Microbe Ecology Interactions

- **Bacterial Rhizostimulation**

  Root-enhanced bacteria cell density

  Enrichment of PAH biodegraders via cometabolism

- **Bacterial Metabolic Enrichment**

  Expansion of bacterial metabolic capabilities

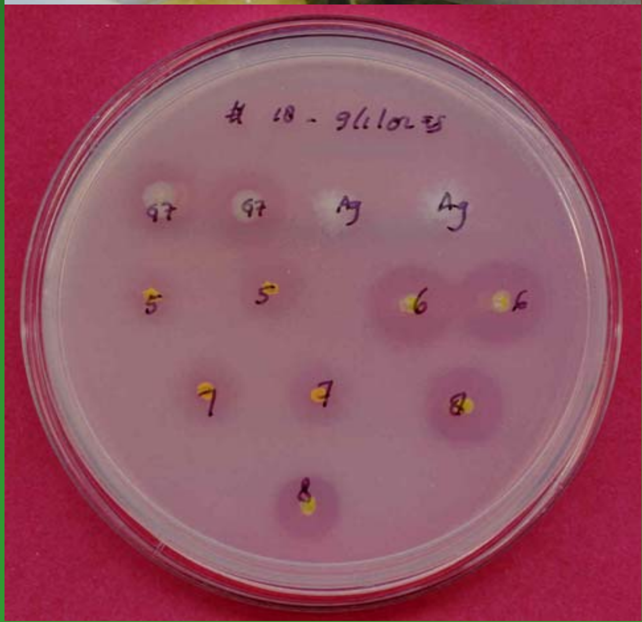
PAH Metabolism Spray Plate Assay

Specific PAH biodegrader assay

Soil extracts plated for CFUs

Phenanthrene residue applied

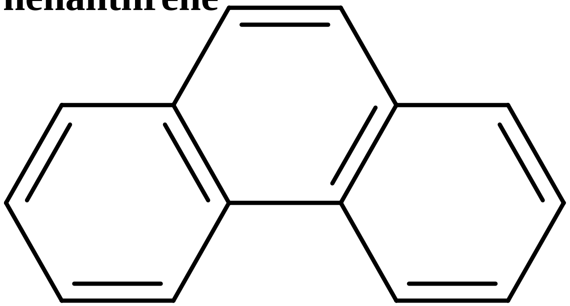
Clear zones = biodegraders = ZFUs



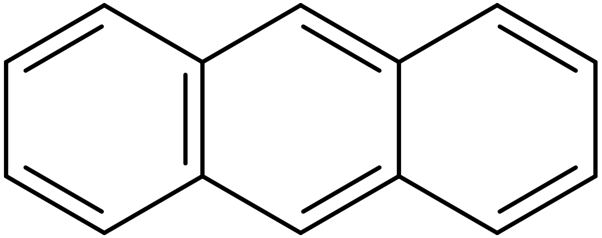
Bacterial Phenanthrene-Degrading Isolates

Spray-Tested against Multiple PAHs

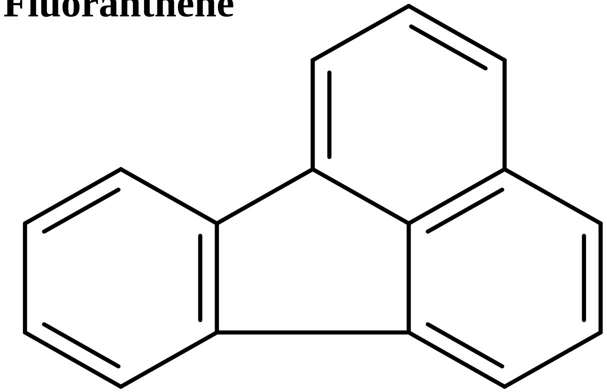
Phenanthrene



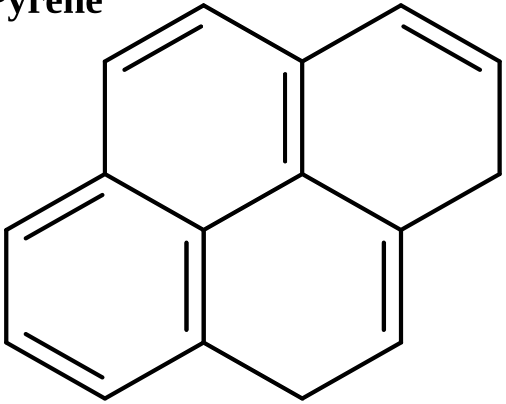
Anthracene



Fluoranthene



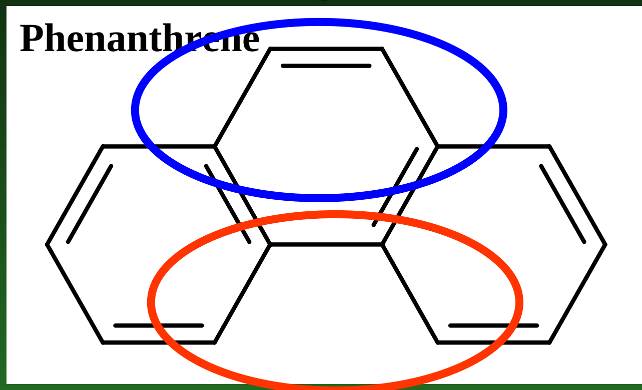
Pyrene



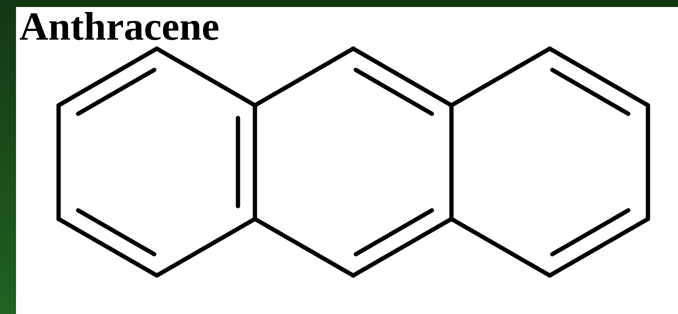
Bacterial Phenanthrene-Degrading Isolates

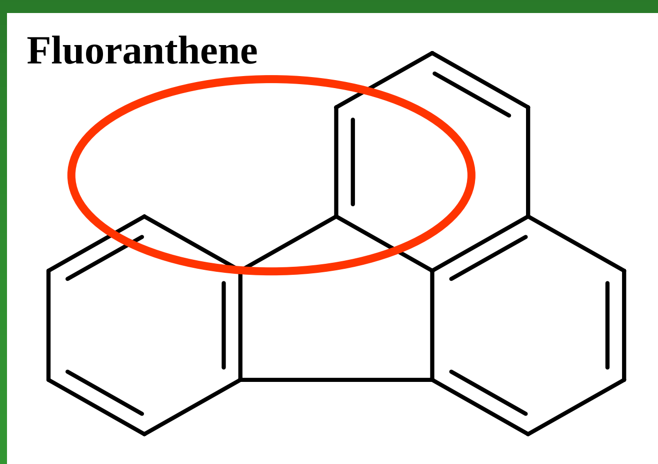
Spray-Tested against Multiple PAHs

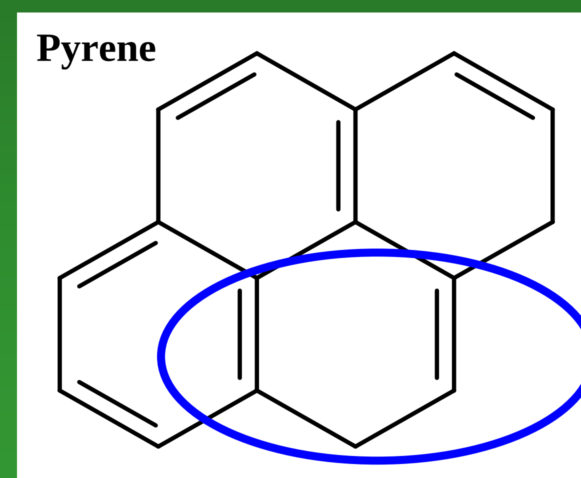
k-region



Bay-region





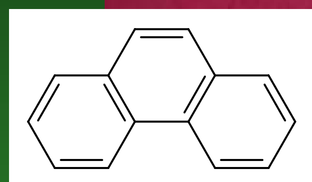


Bacterial Isolates Tested against Multiple PAHs

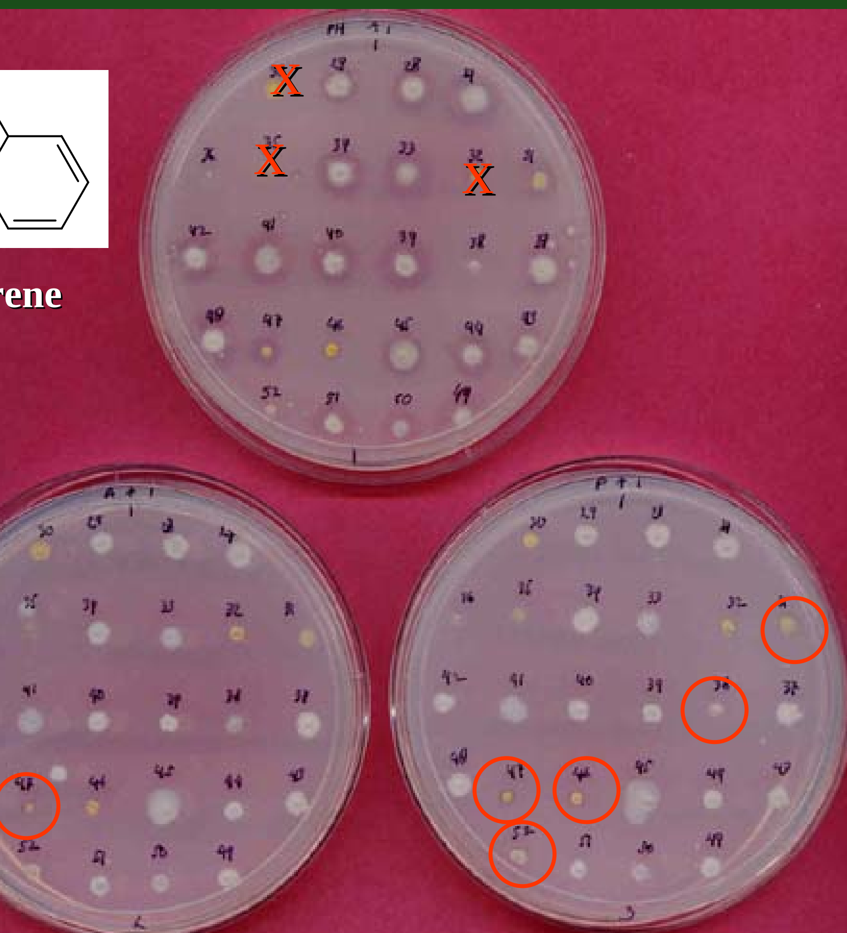
Over 2100 Phenanthrene Degraders Isolated

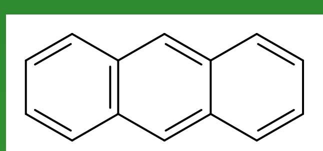
~110 isolates from each Phyto treatment including untreated soils

Phen^{D} isolates Spray-Tested against other PAH compounds

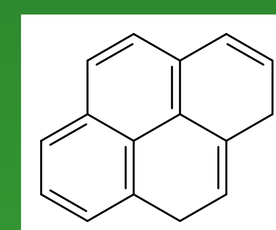


Phenanthrene



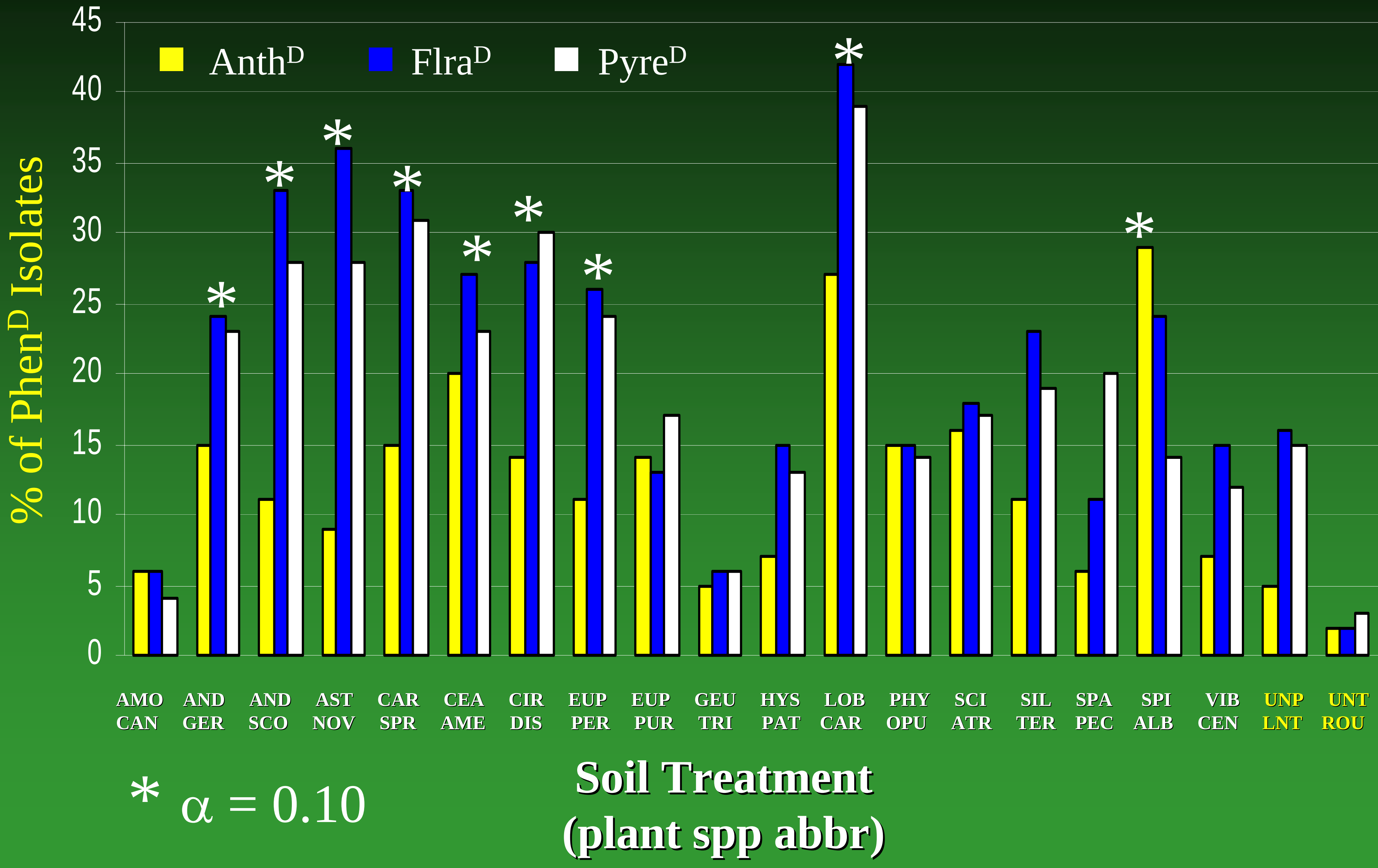


Anthracene



Pyrene

Phenanthrene Degraders tested on other PAHs



* $\alpha = 0.10$

Part III. Community Ecology Influences

- **Vegetated Community Persistence**

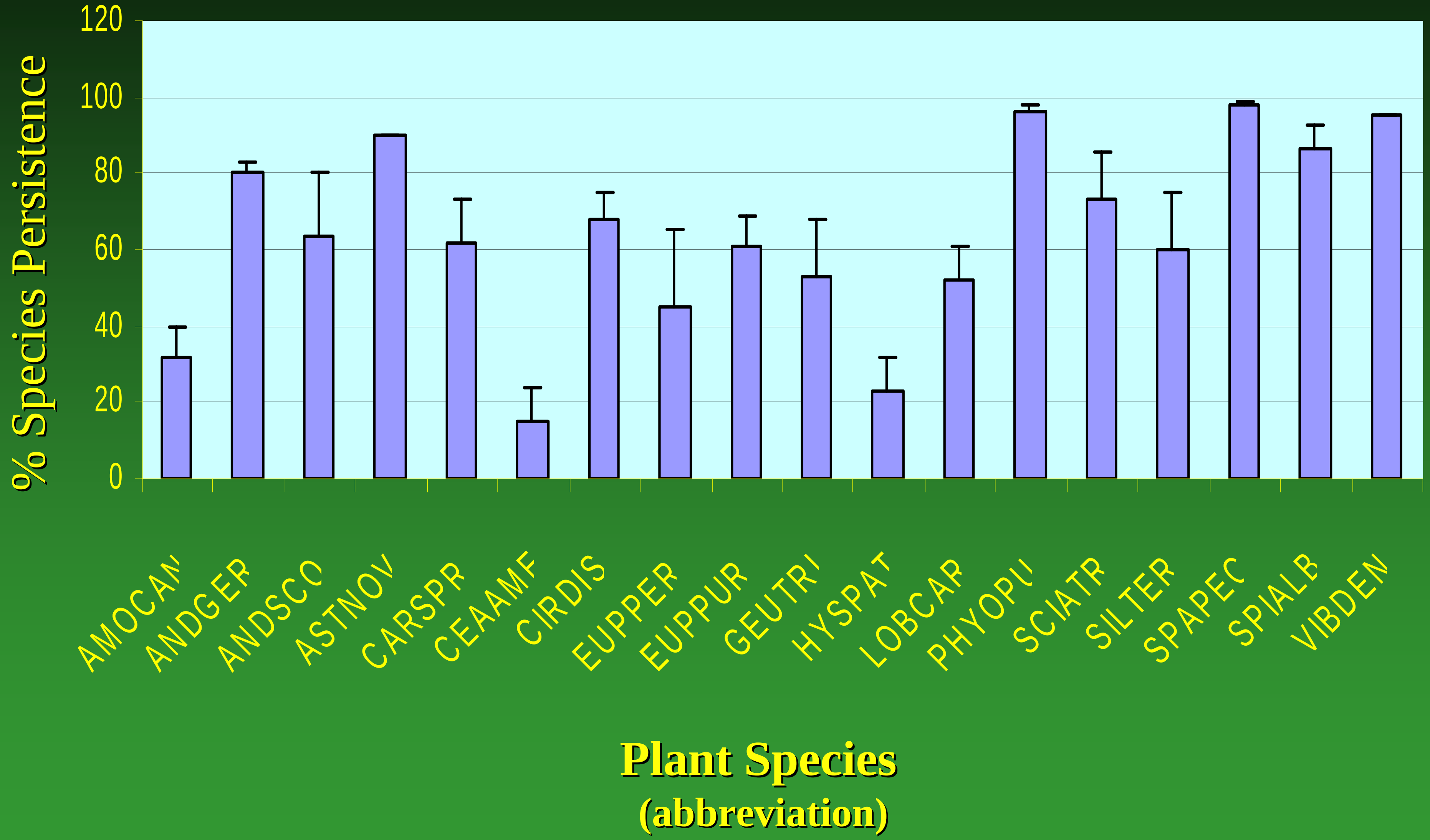
  Field installation strategy

  Susceptibility to herbivores, disease, encroachment

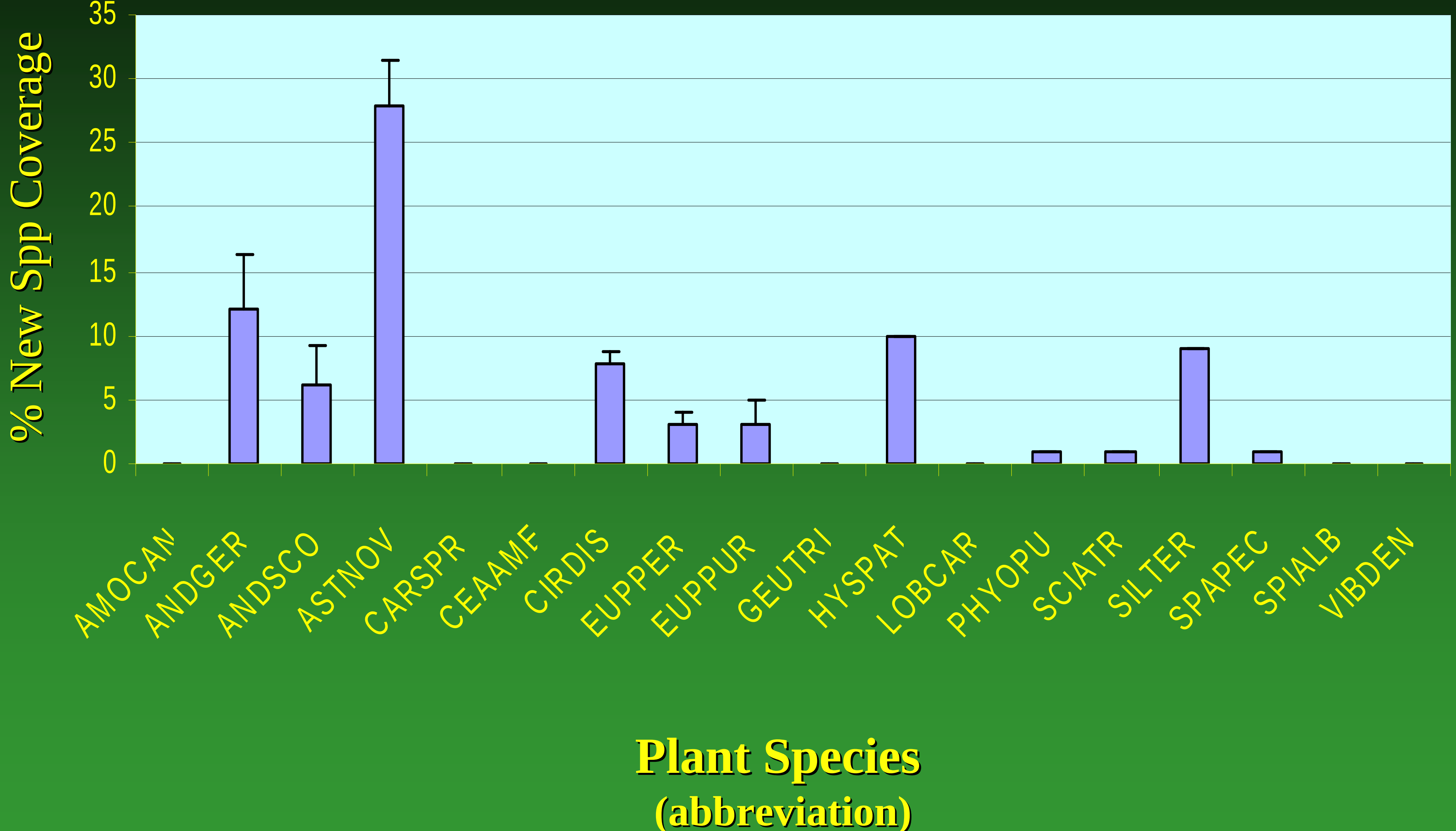
- **Vegetated Community Expansion**

  Self-propagation and competitiveness

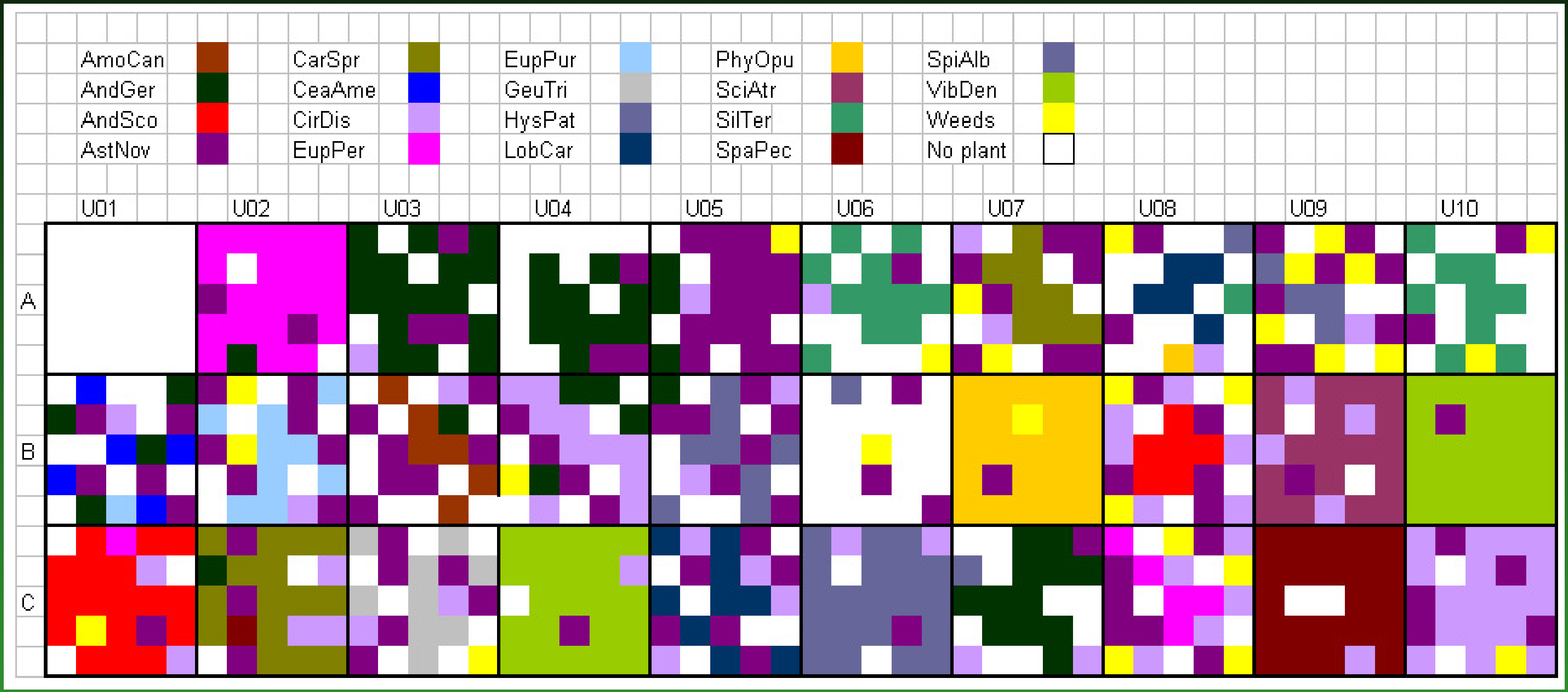
Persistence of Planted Phyto Species (3rd Yr)



Phyto Species Expansion within Plot (3rd Yr)



Relative Density Map of Phyto Community Species



Selected Phyto Species should be perennial, competitive and prolific

Results Summary

Planted treatments were typically more effective at reducing soil PAHs than unplanted treatments

Different plant species had different effects on bacterial biodegrader community

Plants generally enriched broad-range bacterial PAH metabolic capabilities

Varied plant community dynamics among species – some more suitable for stable habitat restoration

Rouge Manufacturing Complex Phytoremediation Trials

Dearborn, MI – May 2003

Planted Fall 02 with ~24,000 Individual Plants

Rouge Phyto Exhibit – Plant Community Subplots

Sp A = Large Shrubs

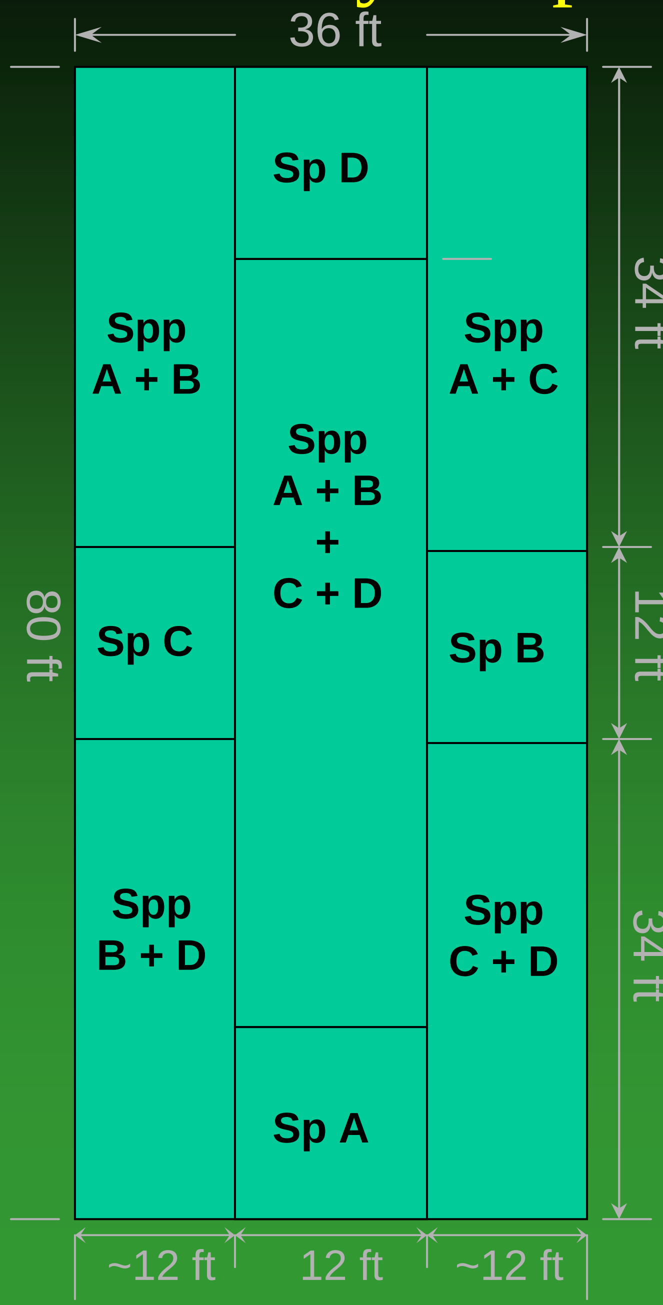
Sp B = Short Grasses

Sp C = Low Shrubs

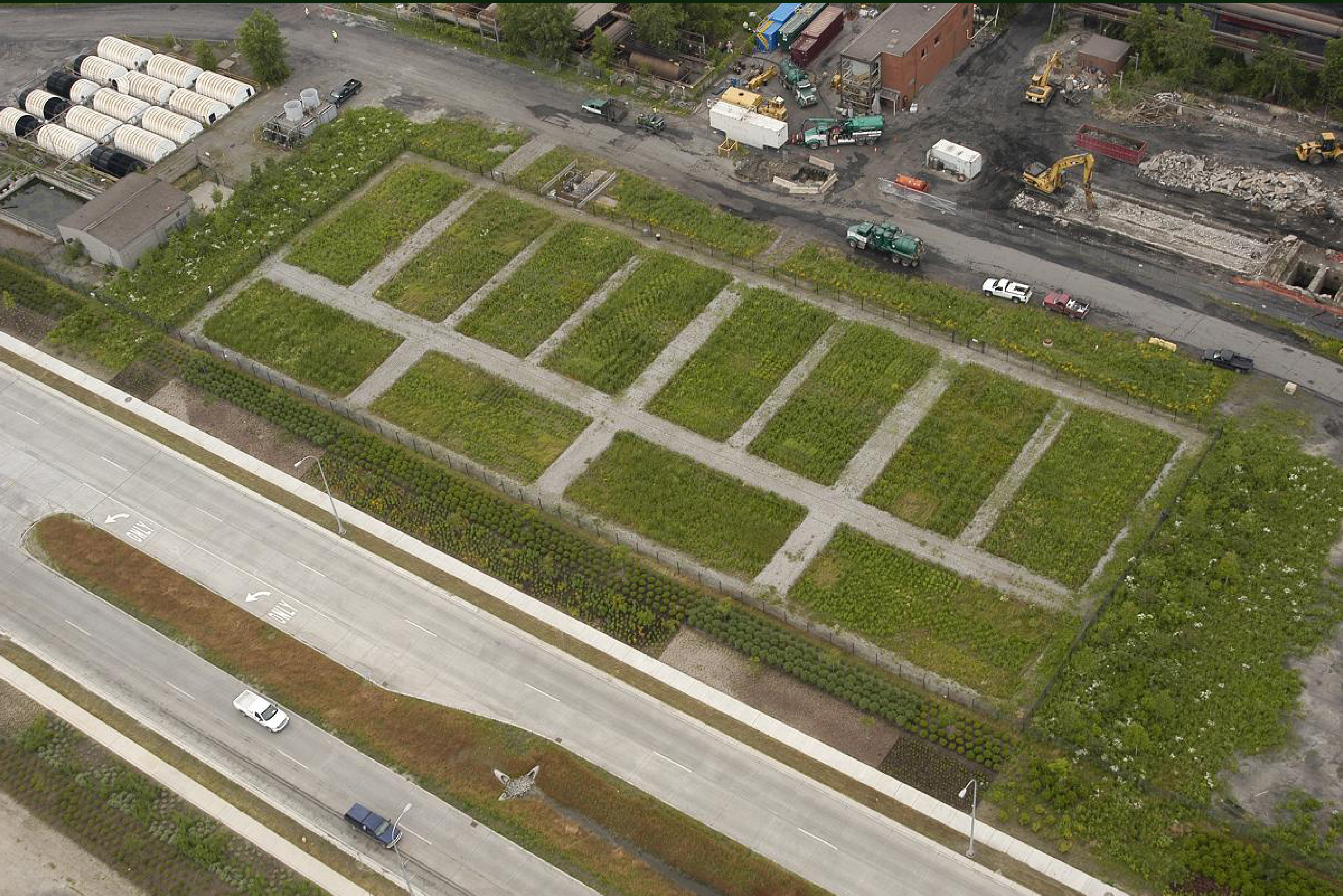
Sp D = Tall Grasses or Trees

12 Plots X 9 Subplots =

108 plant spp combinations



Rouge Phyto Exhibit – June 2004 - Aerial Overview



Rouge Complex Phytoremediation Installation Exhibit
July 2004 – 2nd Season

Wildlife Recovery at the Industrial Brownfield

Protected Species and Pollinators

Wildlife Recovery at the Industrial Brownfield

Protected Species and Pollinators

Habitat and Beneficial Species

Wildlife Recovery at the Industrial Brownfield

Protected Species and Pollinators

Habitat and Beneficial Species

Urban Mammal Migration

Recommended Phyto Species:

Phyto and Weed-resistance rating: * = ok, ** = good, * = excellent**

Habitat: U = upland, W = wetland (low-land),

Type: G = grass, H = herbaceous

Species	Common Name	Phyto	Weed-R	Habitat	Type
Andropogon gerardii	Big Bluestem	***	*	U	G
Aster novae-anglicae	New England Aster	***	***	U or W	H
Carex sprengelii	Sprengel Sedge	**	***	U or W	G
Eupatorium perfoliatum	Boneset	**	***	U or W	H
Eupatorium purpureum	Joe-pye Weed	***	*	U	H
Hystrix patula	Bottlebrush Grass	**	***	U	G
Panicum virgatum	Switchgrass	***	***	U	G
Physocarpus opulifolius	Ninebark	**	***	U	H
Scirpus atrovirens	Green Bulrush	***	***	U or W	G
Solidago patula	Swamp Goldenrod	**	***	U or W	H
Spartina pectinata	Prairie Cordgrass	**	***	U or W	G
Spirea alba	Meadowsweet	***	***	U	H
Viburnum dentatum	Arrowwood Viburnum	**	***	U	H

Potential PARAPHYTOREMEDIATION Species:

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BIOMASS RECOVERY

Biocomposite Plastics – replacement for fossil fuel-derived products

Bioenergy Crops – pelletized high-energy

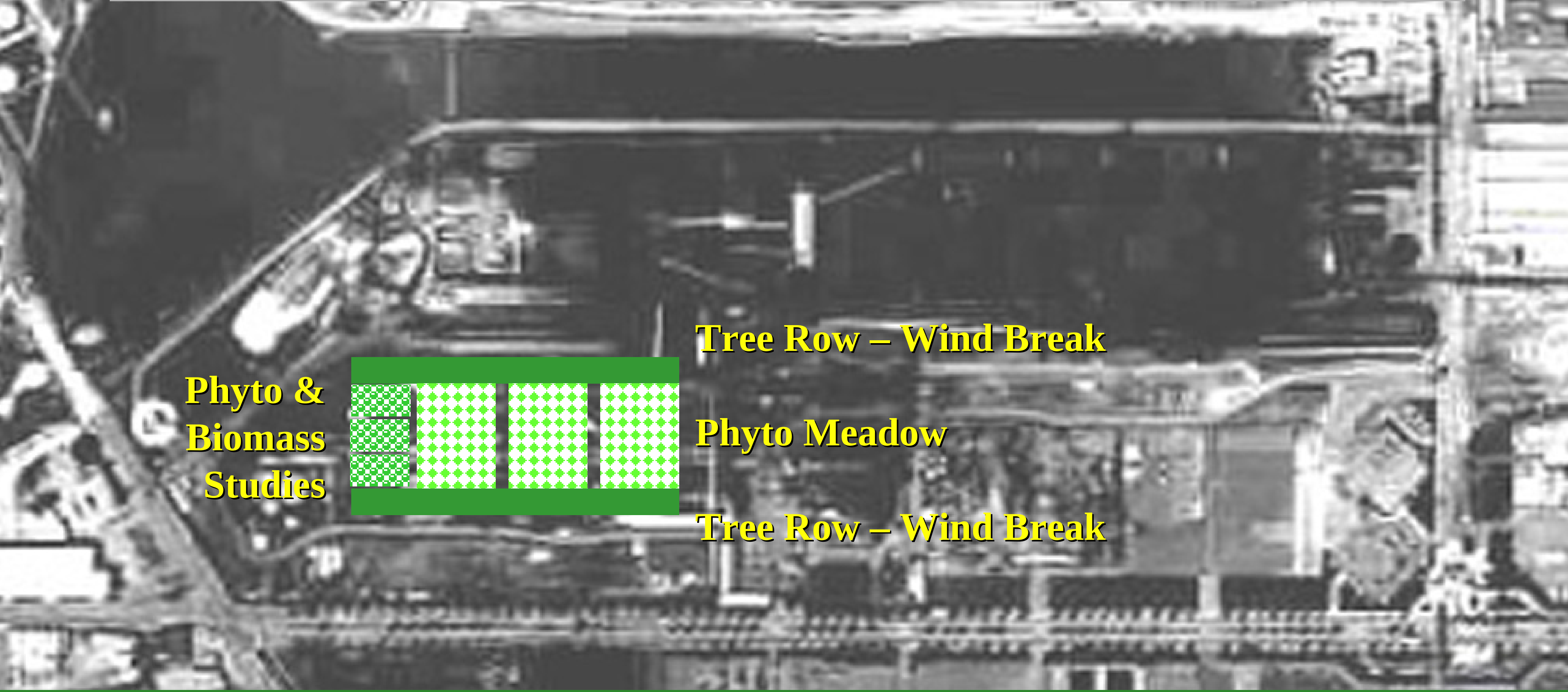
Cellulose Feedstocks – ethanol, etc.

Collaboration with:

Ford Research Labs

MSU Composite Materials Center

Potential Site Redevelopment / Rehabilitation Plan



<u>30 Acre Remediation / Rehabilitation Challenge</u>

Sustainable plant community for site stabilization and intrinsic bioremediation

- ~$8,000 - $20,000 per acre not including labor costs
- Optional industrial, site restoration, and educational opportunities

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Collaborators

MSU Phytoremediation Lab

Ford Research Labs

UMD Plant Physiology Lab

New Mexico State University