

# **An Integrated Multi-process Phytoremediation System for Removal of PAH Contaminants from Soils**

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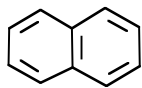
## **WHY Using Plants (Phytoremediation) ?**

- 1. It preserves the natural structure and texture of soil**
- 2. It is driven by solar energy and suitable to various regions and climates**
- 3. It is low in cost and technically feasible**
- 4. It has the potential to provide a sufficient biomass for rapid remediation**
- 5. Restoration is as important as remediation**

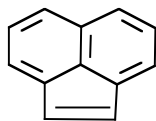
## **WHY Multiple Processes ?**

- 1. Complicatedly mixed contaminants are present in the environment**
- 2. Many techniques based on individual process are failed or ineffective**
- 3. Contaminants are too toxic to plants and bacteria for remediation**
- 4. Employment of multiple, different remediation mechanisms**
- 5. Multiple remediation kinetics resulting in effective and efficient remediation**

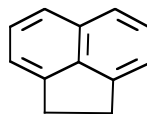
# Sixteen Priority Polycyclic Aromatic Hydrocarbons



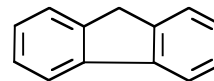
**naphthalene**



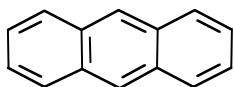
**acenaphthylene**



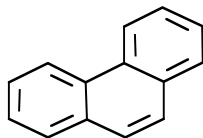
**acenaphthene**



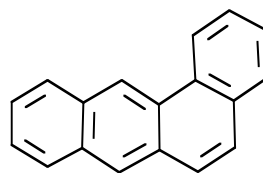
**fluorene**



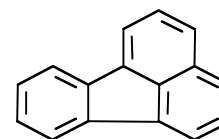
**anthracene**



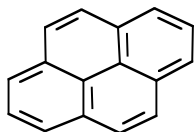
**phenanthrene**



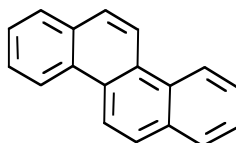
**benzo(a)anthracene**



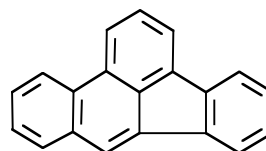
**fluoranthene**



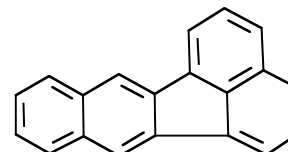
**pyrene**



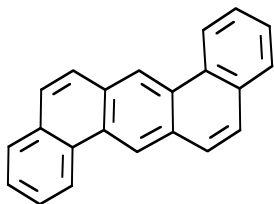
**chrysene**



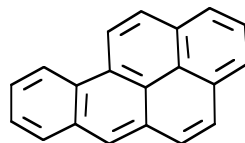
**benzo(k)fluoranthene**



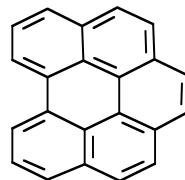
**benzo(b)fluoranthene**



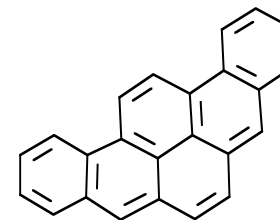
**dienzo(a,i)anthracene**



**benzo(a)pyrene**

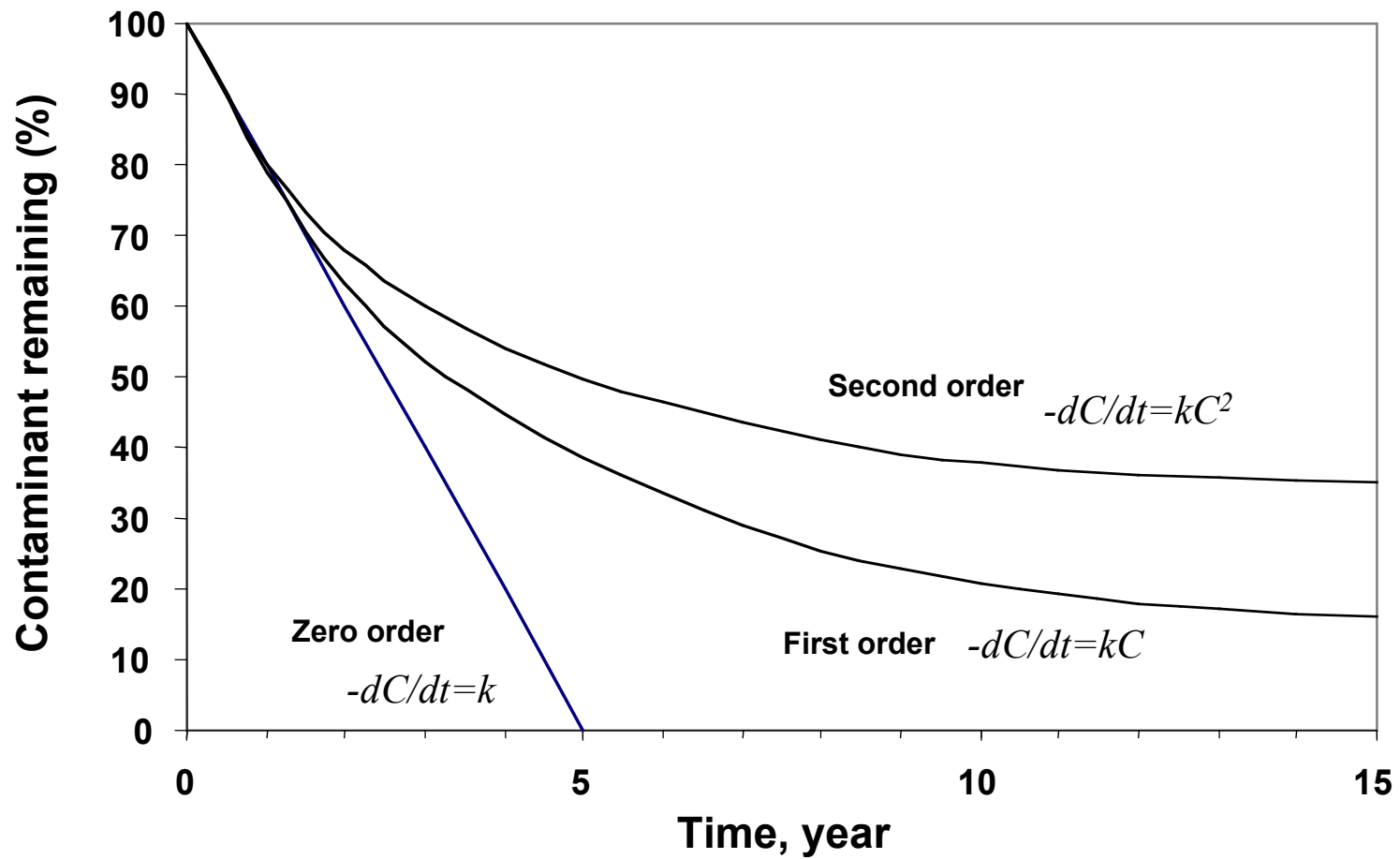


**benzo(g,h,i)perylene**

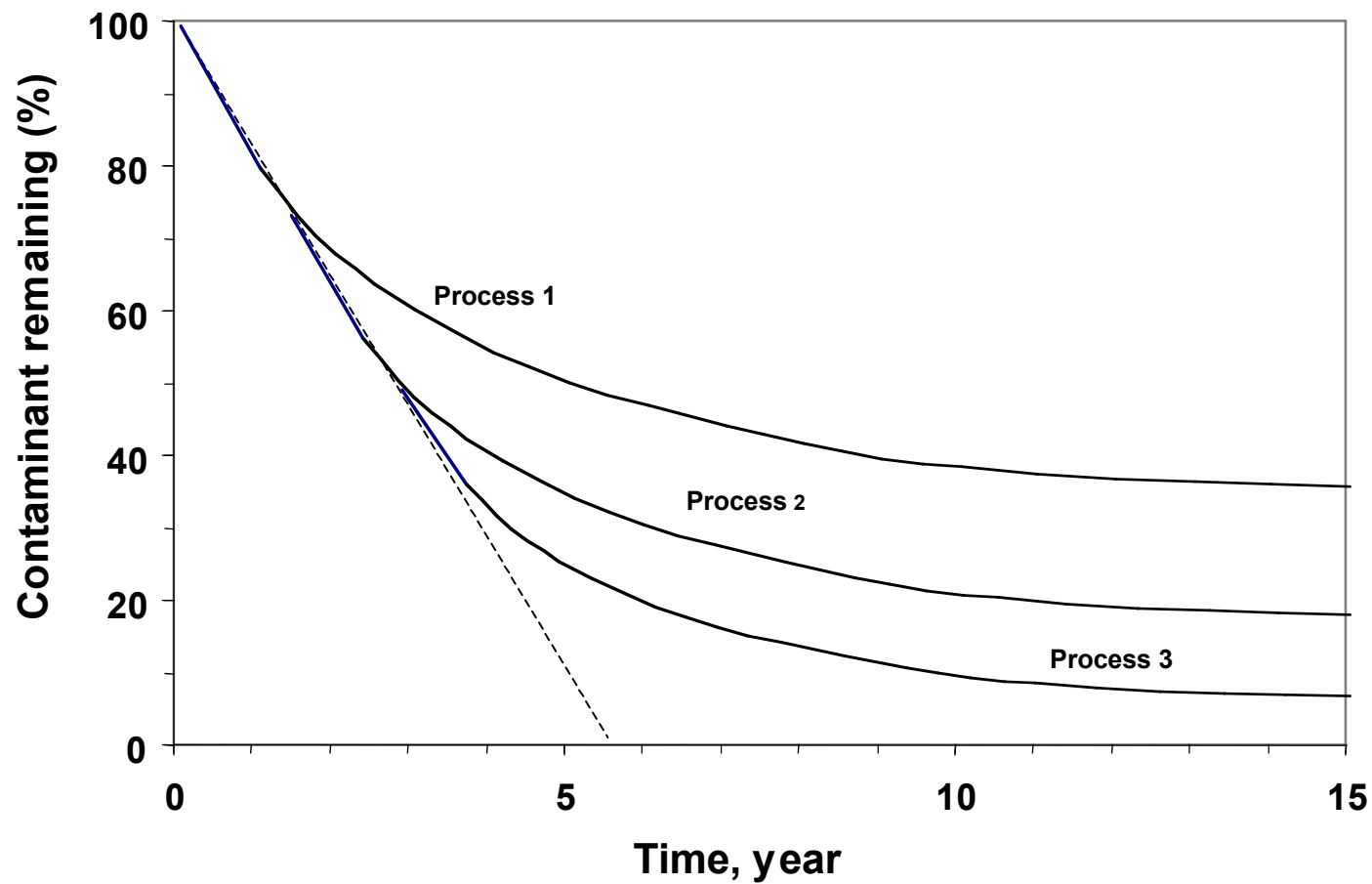


**dibenzo(a,i)pyrene**

## Three Types of Kinetics Observed for Contaminant Remediation



## Pseudo Zero Order Kinetics of Successive Application of Three Different Processes



## Design of an Integrated Multi-process System for Removal of PAHs:

<u>Technique</u>	<u>Remediation Process</u>	<u>Targeted Contaminants</u>
Land Farming	Volatilization	Naphthalene Acenaphthene Acenaphthylene
	Photooxidation	Fluorene Anthracene Phenanthrene Benzo(a)anthracene
Bioremediation	Microbial Degradation	Fluoranthene Pyrene Benzo(b)fluoranthene
Phytoremediation	Phytodegradation	Chrysene
	Rhizosphere degradation	Benzo(k)fluoranthene Dibenzo(a,i)pyrene Benzo(a)pyrene Benzo(g,h,i)perylene Dibenzo(a,i)anthracene

## **Experimental Design:**

### **Land farming:**

- 1. Turn-over the soil for exposure to light and air**
- 2. Light is solar simulated radiation**
- 3. Turn-over and water the soil twice a week**

### **Bioremediation:**

- 1. Inoculation of PAH degrading bacteria**
- 2. Water twice a week**

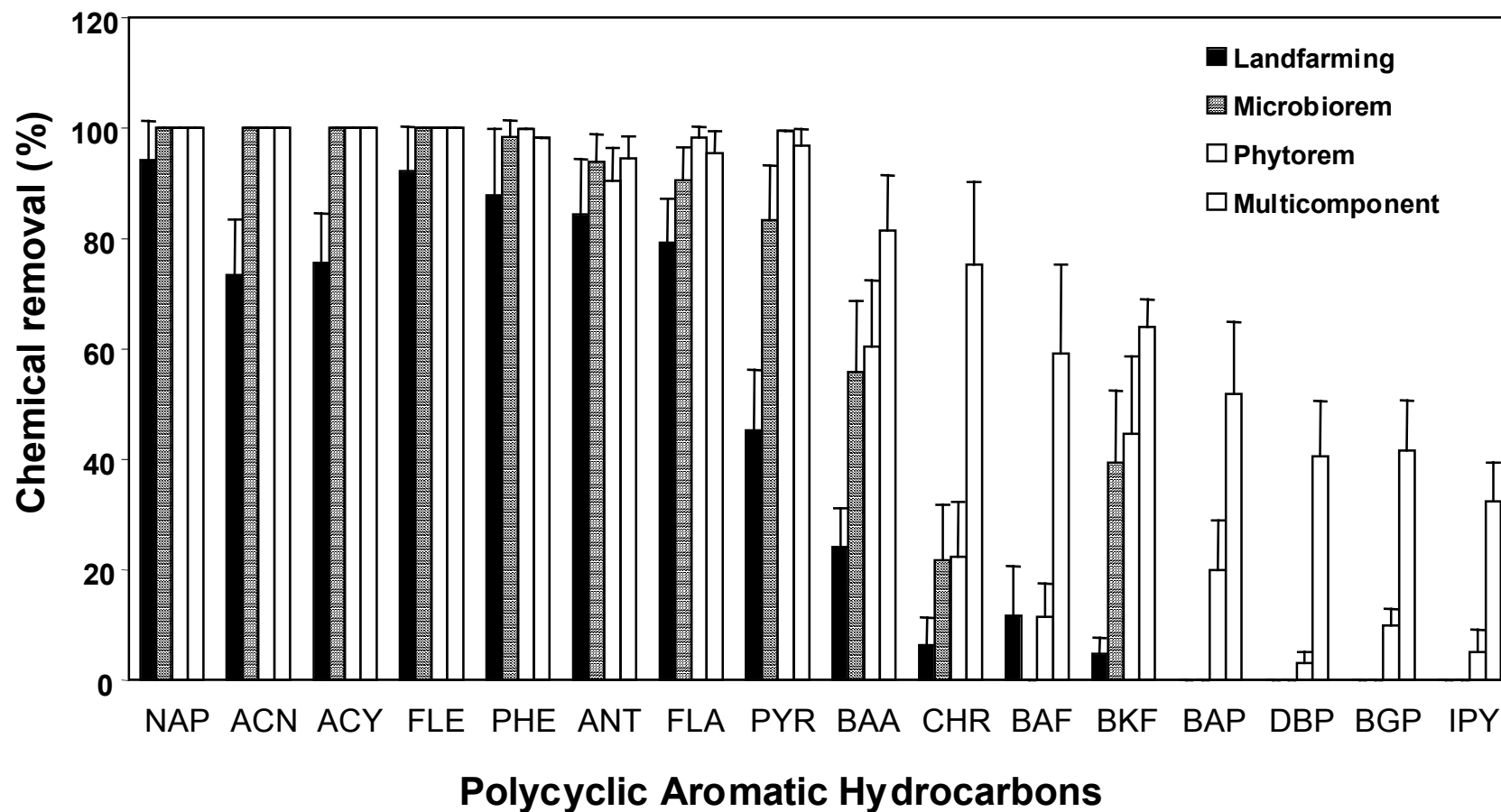
### **Phytoremediation:**

- 1. Growth of plants on the soil**
- 2. Water twice a week**

### **Multi-process system:**

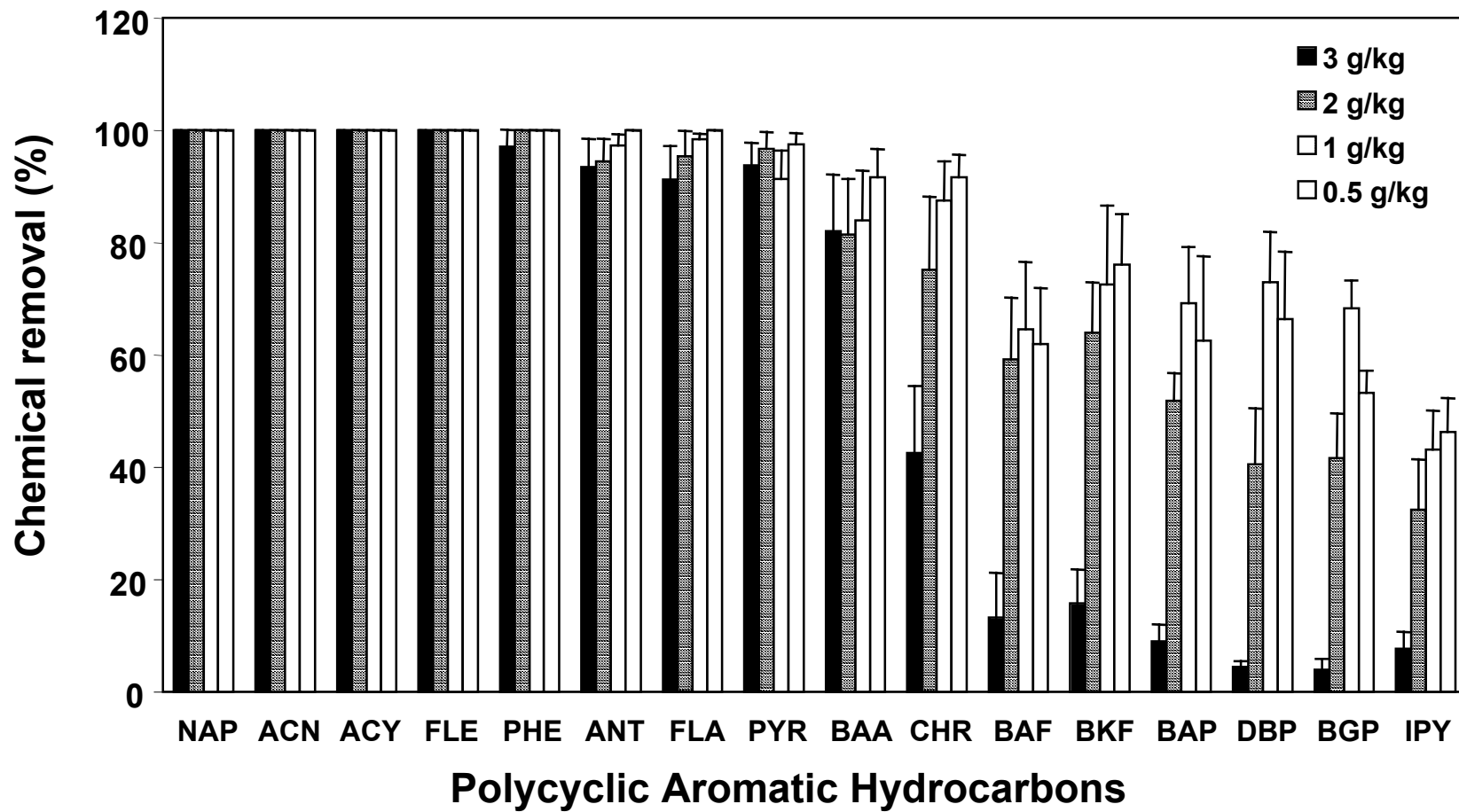
- 1. Land farming the soil for two weeks**
- 2. Inoculation of PAH degrading bacteria**
- 3. Growth of plants with PGPR on the land farmed and bacteria inoculated soil**
- 5. Water twice a week**

## Efficiency of the Different Components for PAH Removal from soil

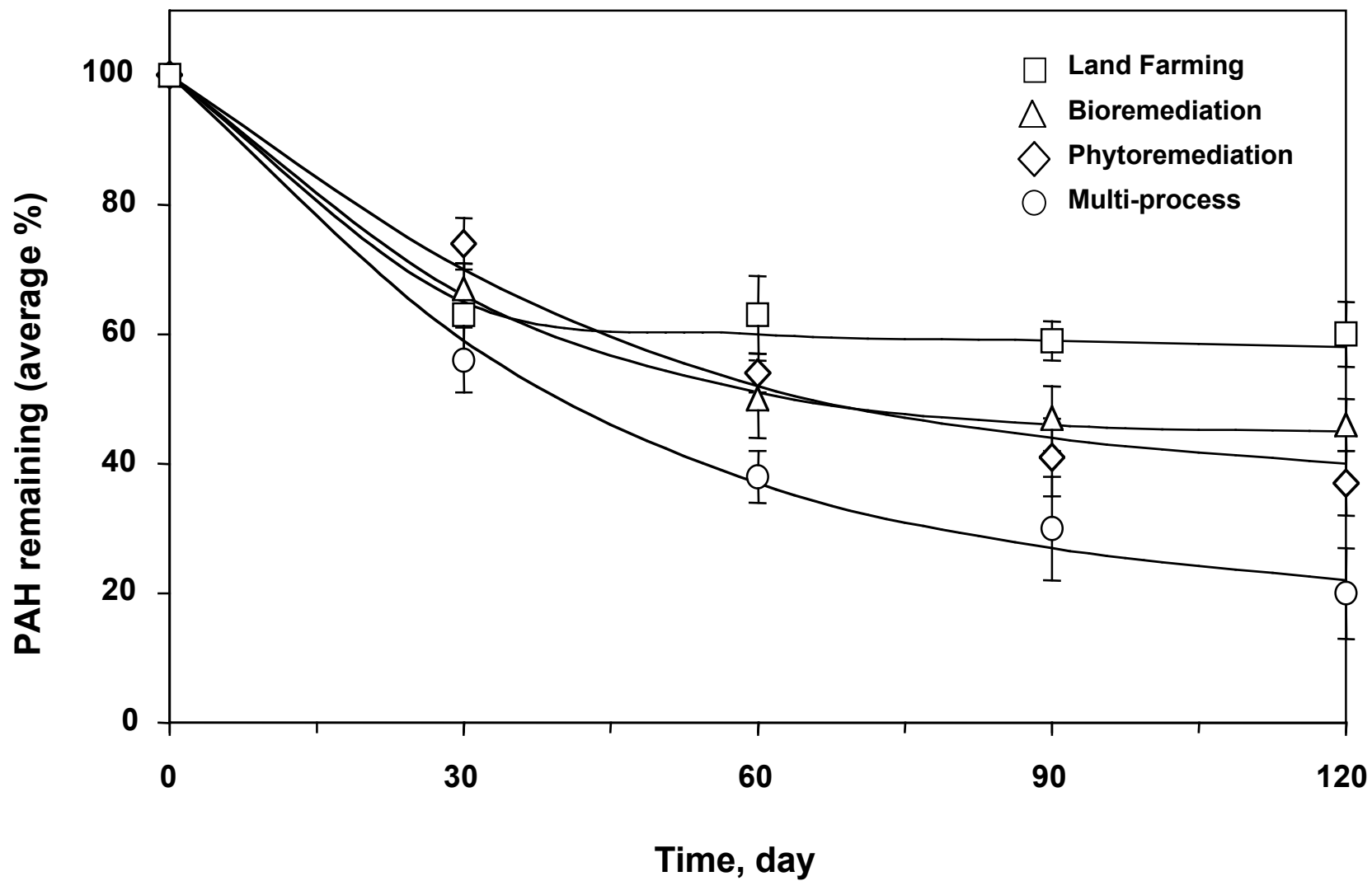




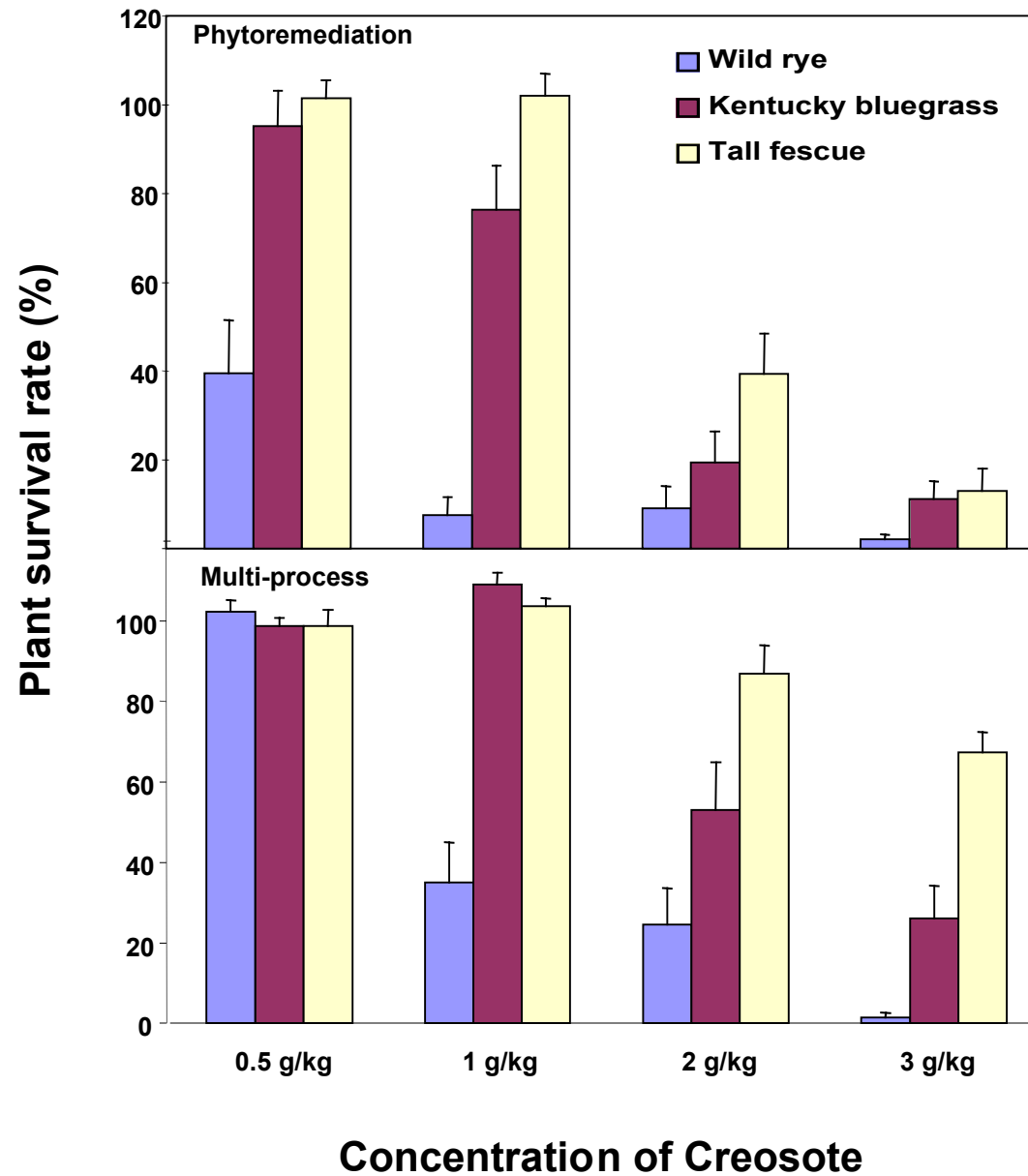
## Efficiency of the Multi-process System for PAH Removal at Different Concentrations



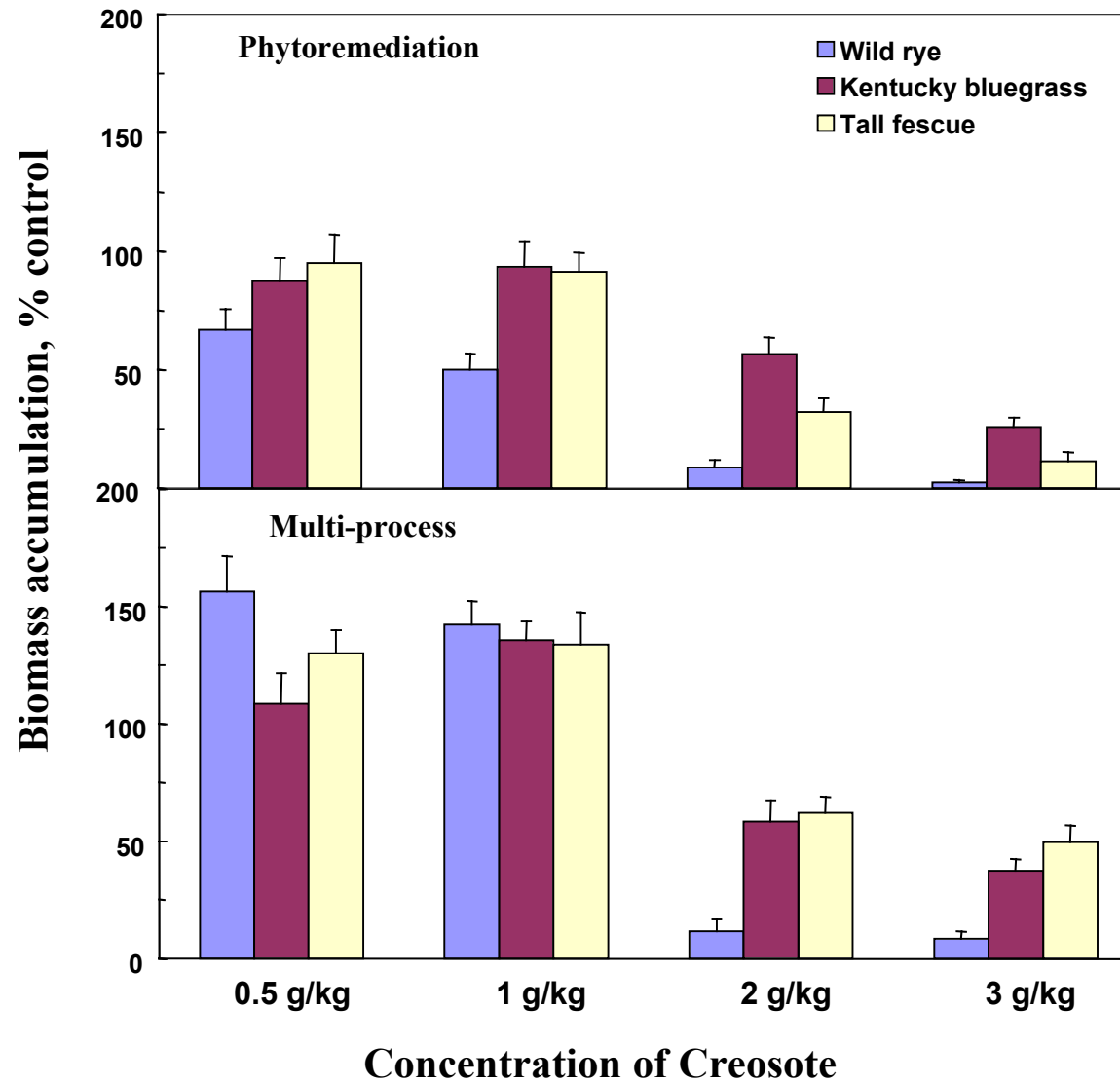
## Pseudo Zero Order Kinetics of the Multi-process System for Removal of PAHs from soil



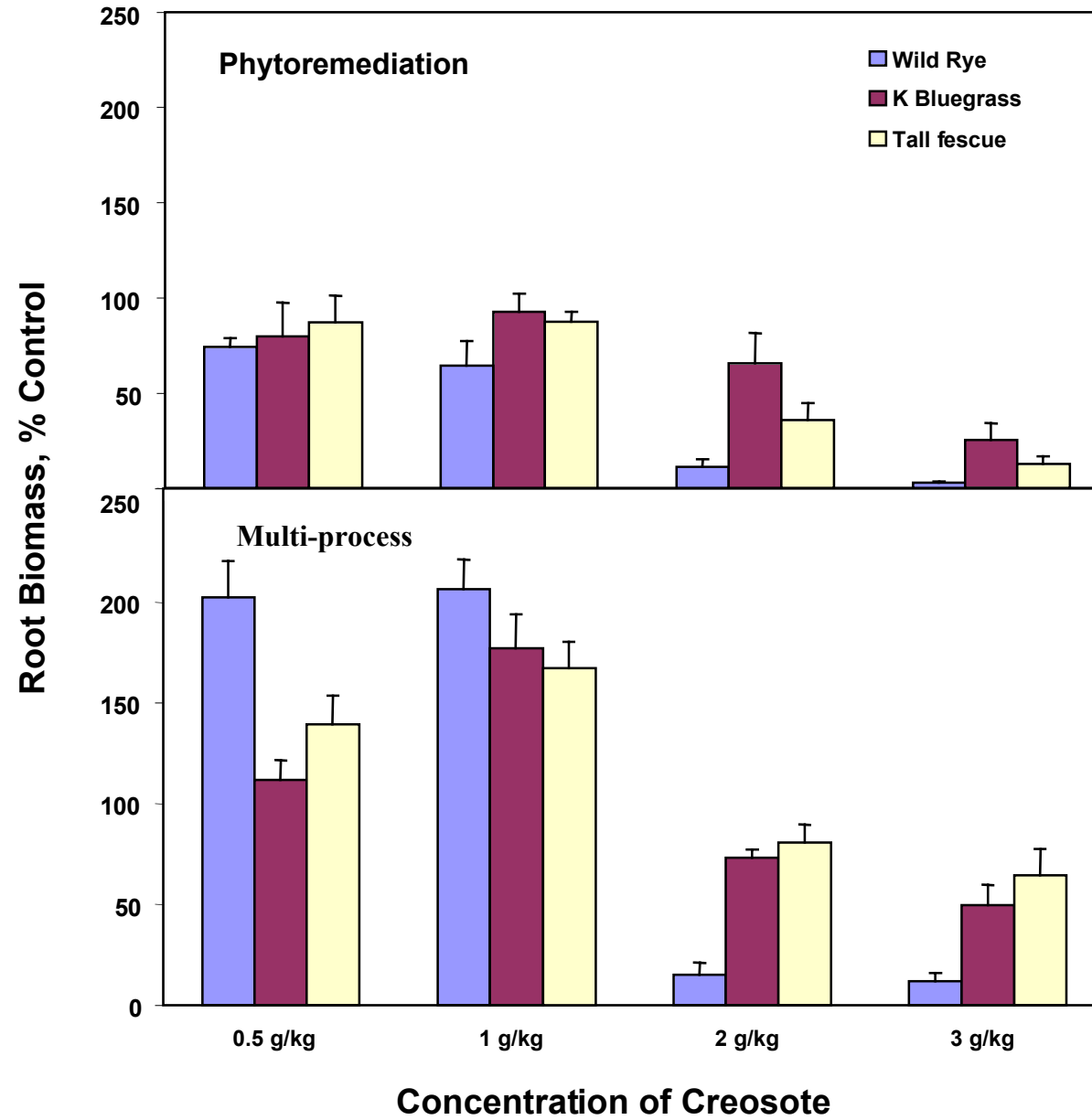
## Growth of Remediation Plant on Contaminated Soil



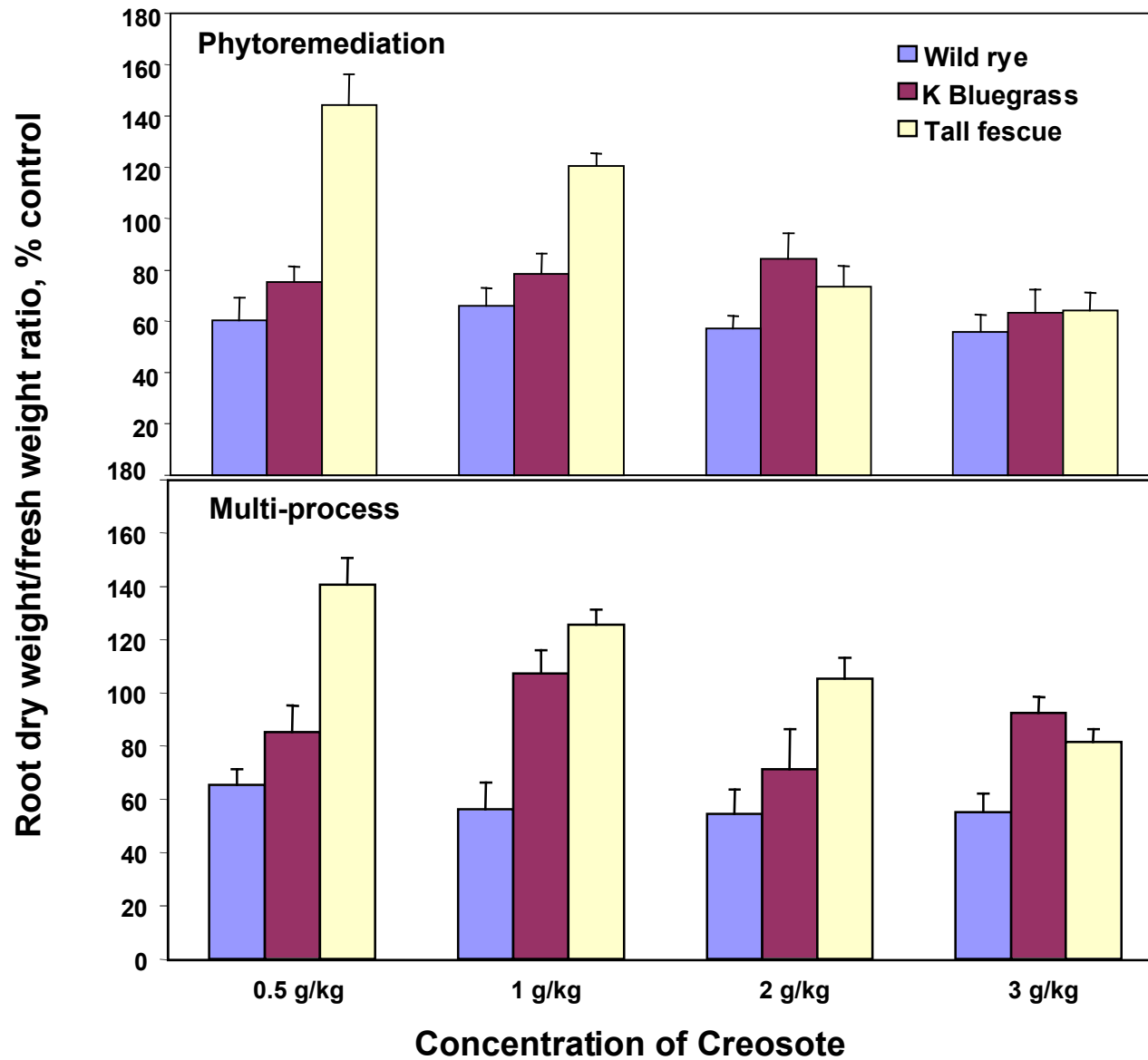
## Total Biomass Accumulation of Remediation Plants



# Root Biomass Accumulation of Remediation Plants



## Root Dry Weight/Fresh Weight Ratio of Remediation Plants



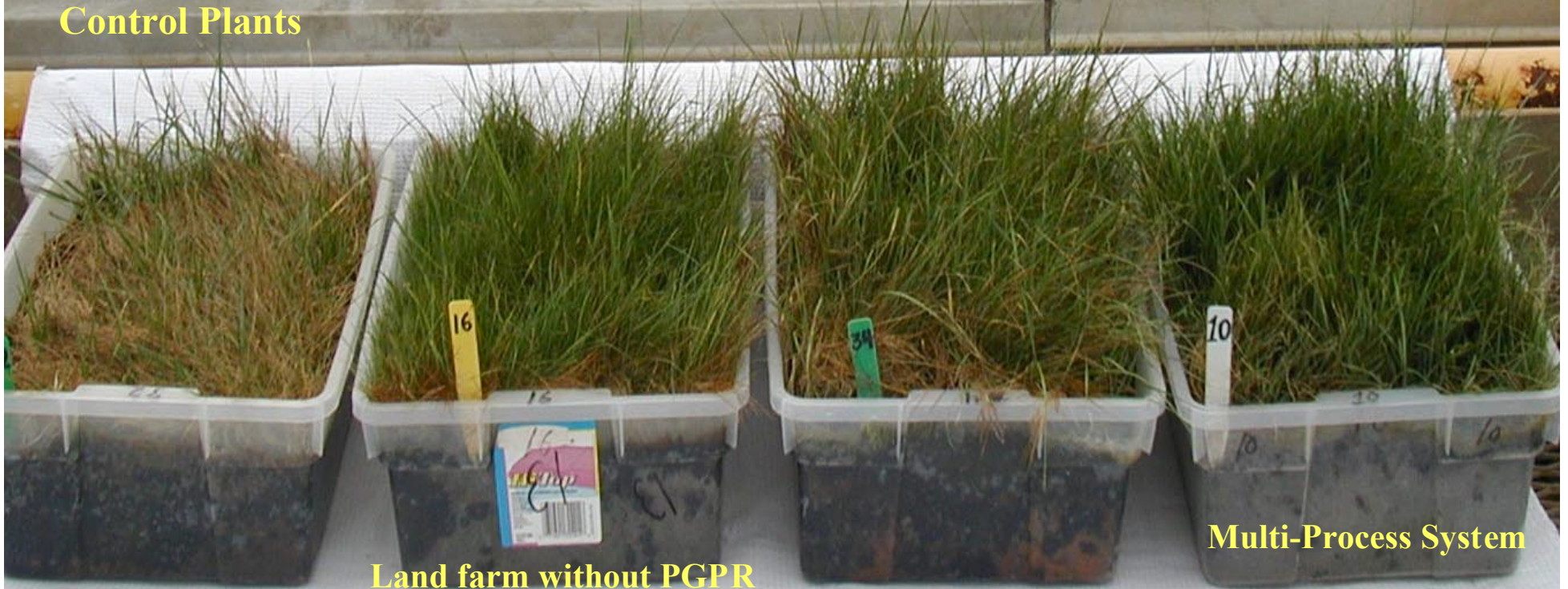
# Effects of Each Process in the Multi-Process Phytoremediation System for Remediation of Oil Sludge Contaminated Soil

Control Plants

with PGPR

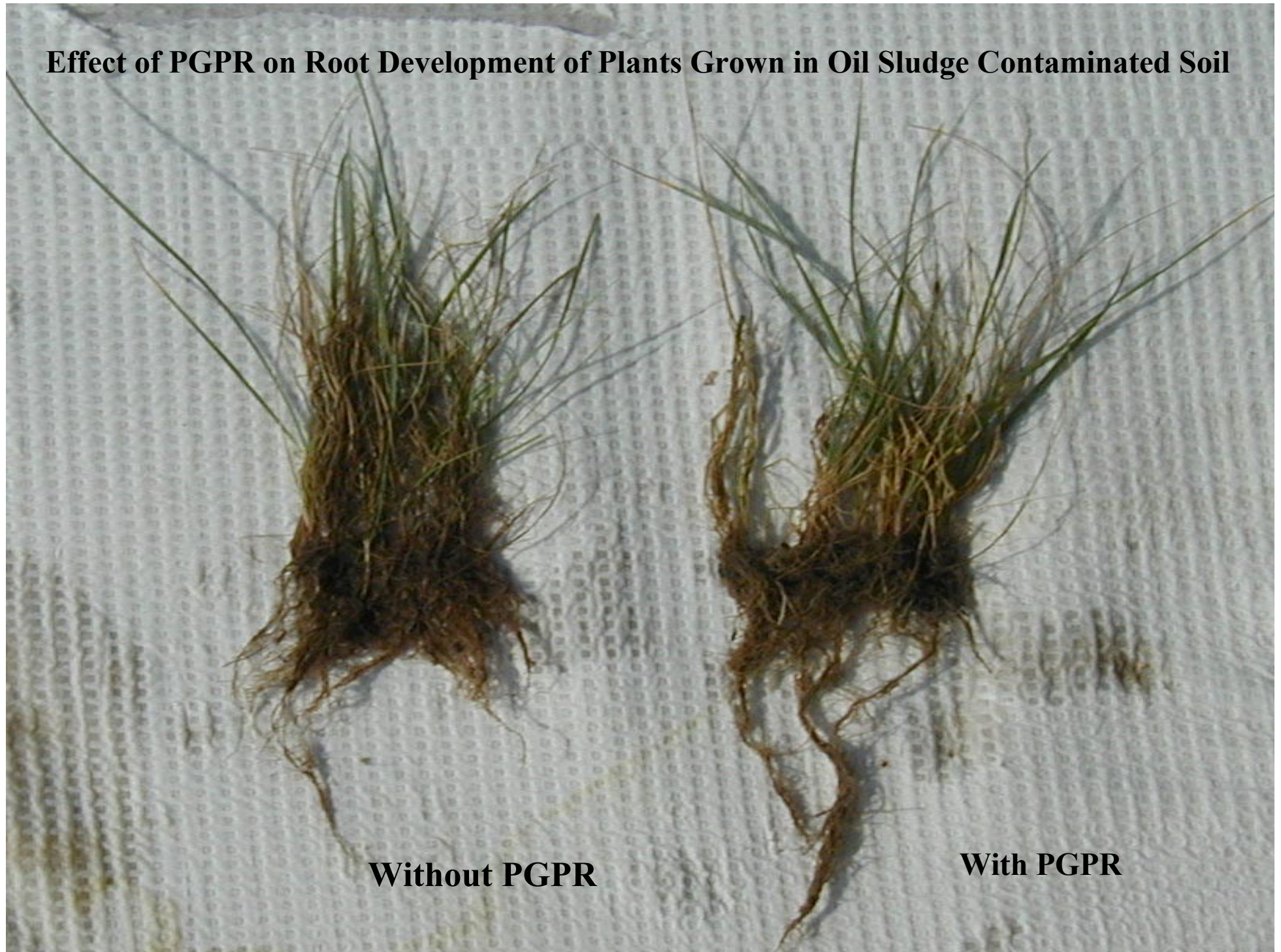
Land farm without PGPR

Multi-Process System





## **Effect of PGPR on Root Development of Plants Grown in Oil Sludge Contaminated Soil**



**Without PGPR**

**With PGPR**



# Field Application of Cocktail Bacteria for Remediation of Herbicide Residues and Rice Growth Promotion

Effect of PGPR on Rice Affected by Herbicide Residues

Effect of Herbicide Residues on Rice



## **Conclusions:**

- 1. Designed phytoremediation has a great potential to be an effective and rapid means to clean up soil contamination.**
- 2. Remediation techniques based on a single process have their limits to deal with complex mixture of contamination.**
- 3. Application of multiple techniques can overcome the limitations of phytoremediation.**
- 4. Development of remediation technology based on multiple processes may be the optimal solution for cleanup contaminated environments.**
- 5. Effort from all sectors to research and develop this technology is definitely needed, plant scientists, soil scientists, microbiologists, environmental chemists, ecologists, toxicologists, environmental engineers et al.**

## **Acknowledgments:**

### **Collaborators:**

**Dr. Bruce Greenberg**

**Dr. Bernard Glick**

**Dr. George Dixon**

### **Working Staff:**

**Mark Lampi**

**Donna Penrose**

**Yousef El-Alawi**

**Shangning Ji**

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