Phytoremediation as a biotechnological tool for environmental restoration

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Layout of the presentation

I – Phytoremediation: scope of application to environmental restoration

II – Case study I – tannery wastewater treatment

III - Case study II – restoration of industrial sediments

IV - Case study III – metal uptake from contaminated soil

V - Case study IV – sustainable forestry

I – Phytoremediation: scope of application to environmental restoration

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Phytoremediation

"...is an emergent technology that uses plants (and rhizosphere microorganisms) to remove, degrade or immobilize chemical contaminants from polluted soils, sediments and water".

Phytoremediation – Why?

Advantages

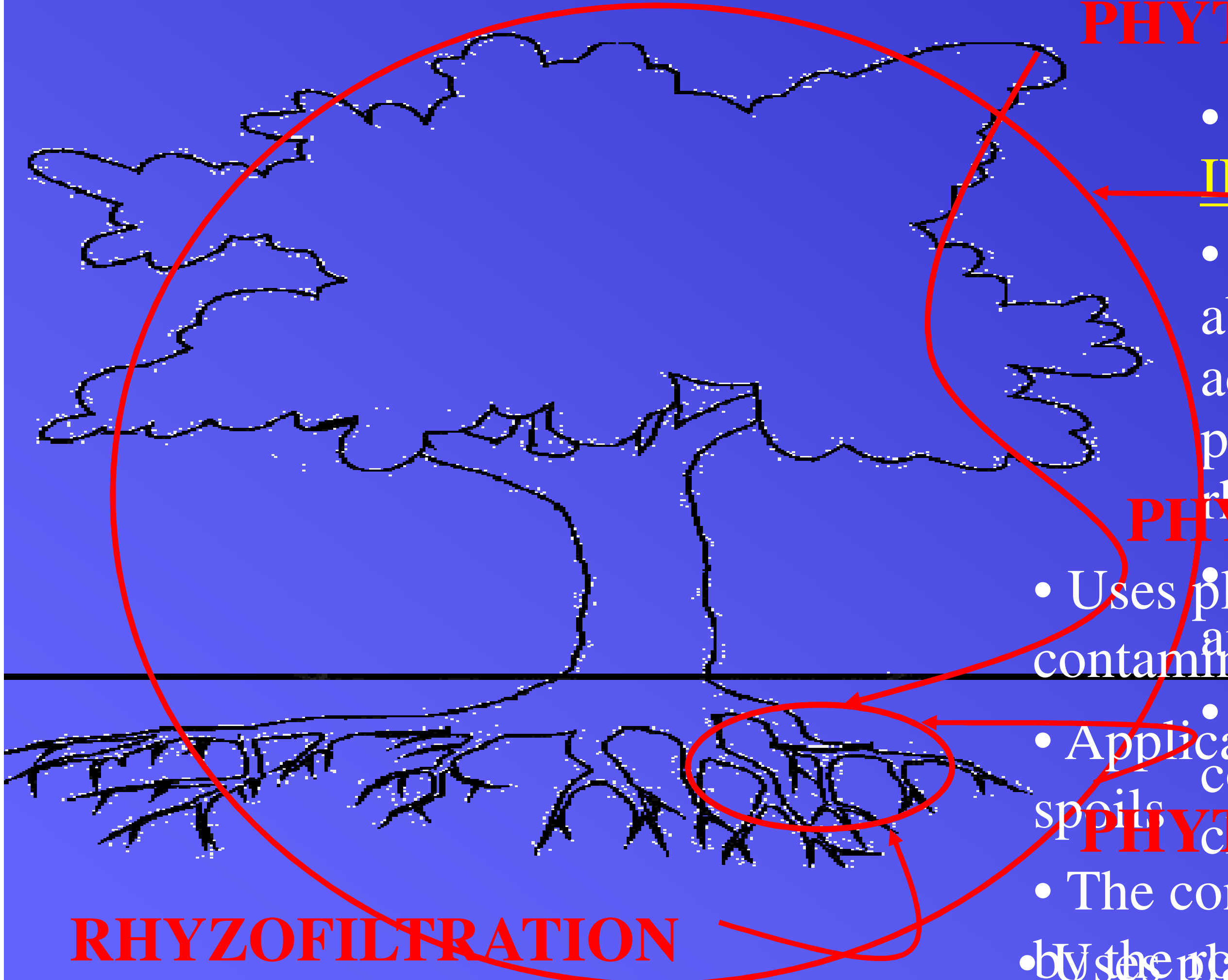
- ☑ Performed *in situ*
- ☑ Cost reduction
- ☑ Acceptance from the public and regulatory agencies
- ☑ No disturbance to the landscape

SUSTAINABLE TECHNOLOGY

Disadvantages

- ☒ High concentrations of the contaminant may become toxic to the plants
- ☒ Contamination risk of the food chain through animal consumption
- ☒ Takes long periods of time

PHYTOREMEDIATION TECHNIQUES



PHYTOSTABILIZATION

- Uses plants to IMOBILIZE contaminants
- Contaminants are absorbed by roots and accumulated or precipitated within the rhizosphere in stable forms
- Applicable for water, soil and mine spoils
- Reduces risk of including contaminants in the food chain

PHYTOEXTRACTION

- Uses plants to REMEDIATE contaminated sites
- Applicable for soil and mine spoils
- The contaminants are captured by the roots and translocated to aboveground parts of the plants

PHYTODEGRADATION

- Uses plants to REMEDIATE contaminated sites
- Degradation of organic pollutants by plants and associated microorganisms

RHYZOFILTRATION

- Uses plants to REMEDIATE contaminated water
- Contaminants are captured by the roots
- The process may be aided by rhizosphere microorganisms

Phytoremediation - water and soil

Constructed wetlands

Diferent plants and growth substrates

Wastewater treatment

Metal uptake by local plants

Effect of mycorrhiza

Mycorrhizal fungi

Isolation

Field trials

Plant growth on stressed and polluted sites

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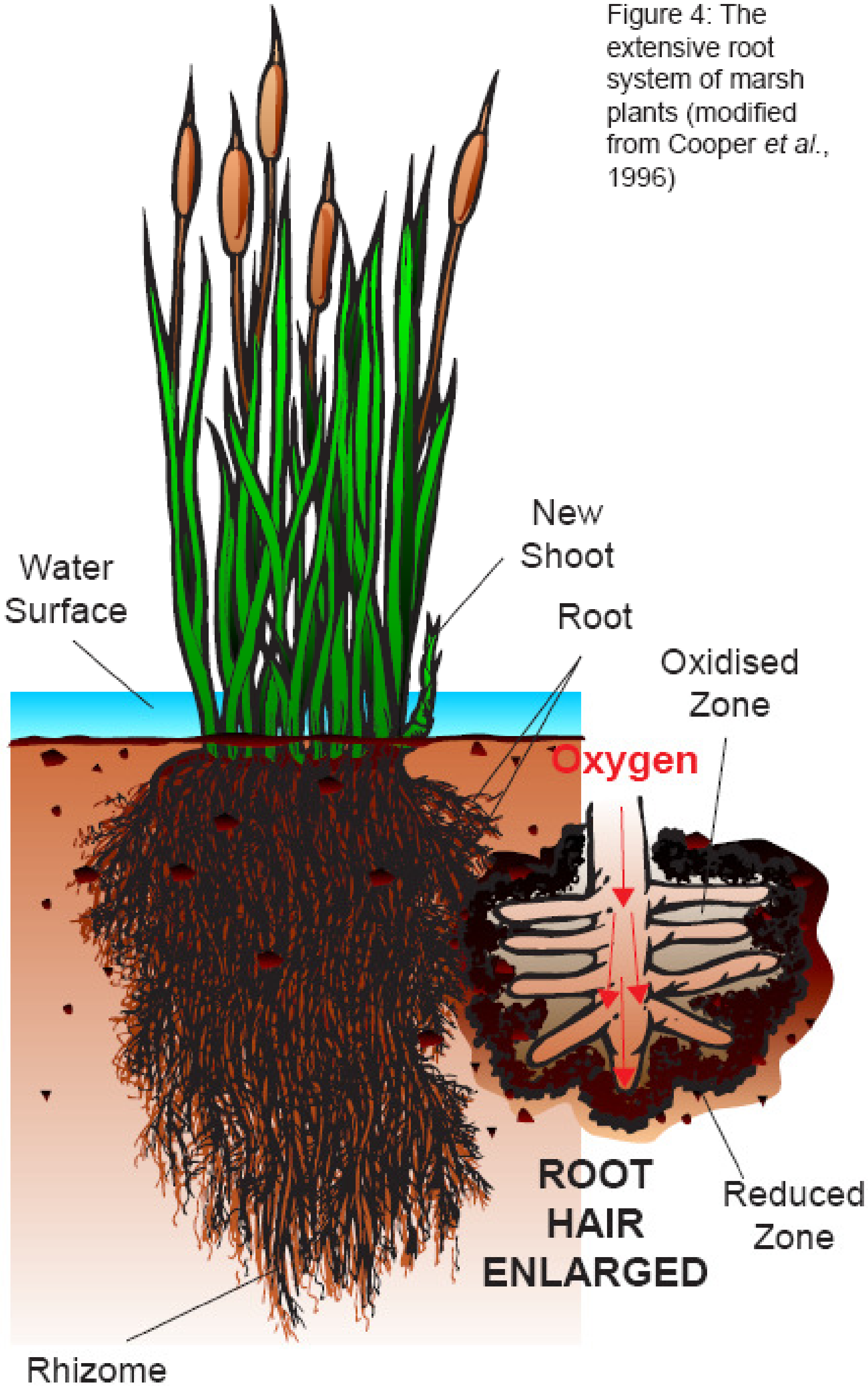
Figure 4: The extensive root system of marsh plants (modified from Cooper *et al.*, 1996)

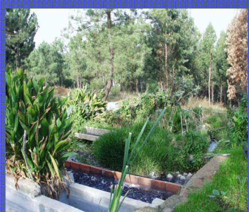


Removal of organic and inorganic contamination from wastewater

➡ Microbial degradation in bulk soil or rhizosphere

Case study:

Tannery industry

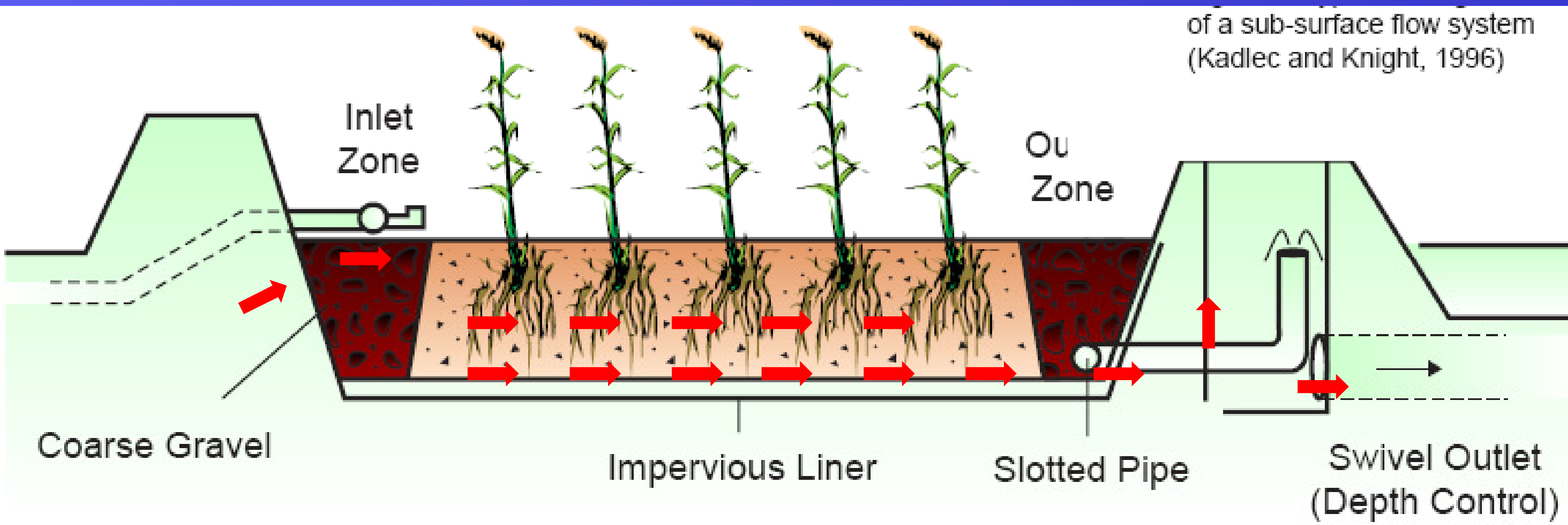


Wastewater:

- High organic loading
- Suspended solids
- Chromium

Phytotoxic effluent

Constructed wetlands
Sub-surface Horizontal Flow



Typical configuration of a sub-surface flow system

(Kadlec and Knight, 1996)

Plant species

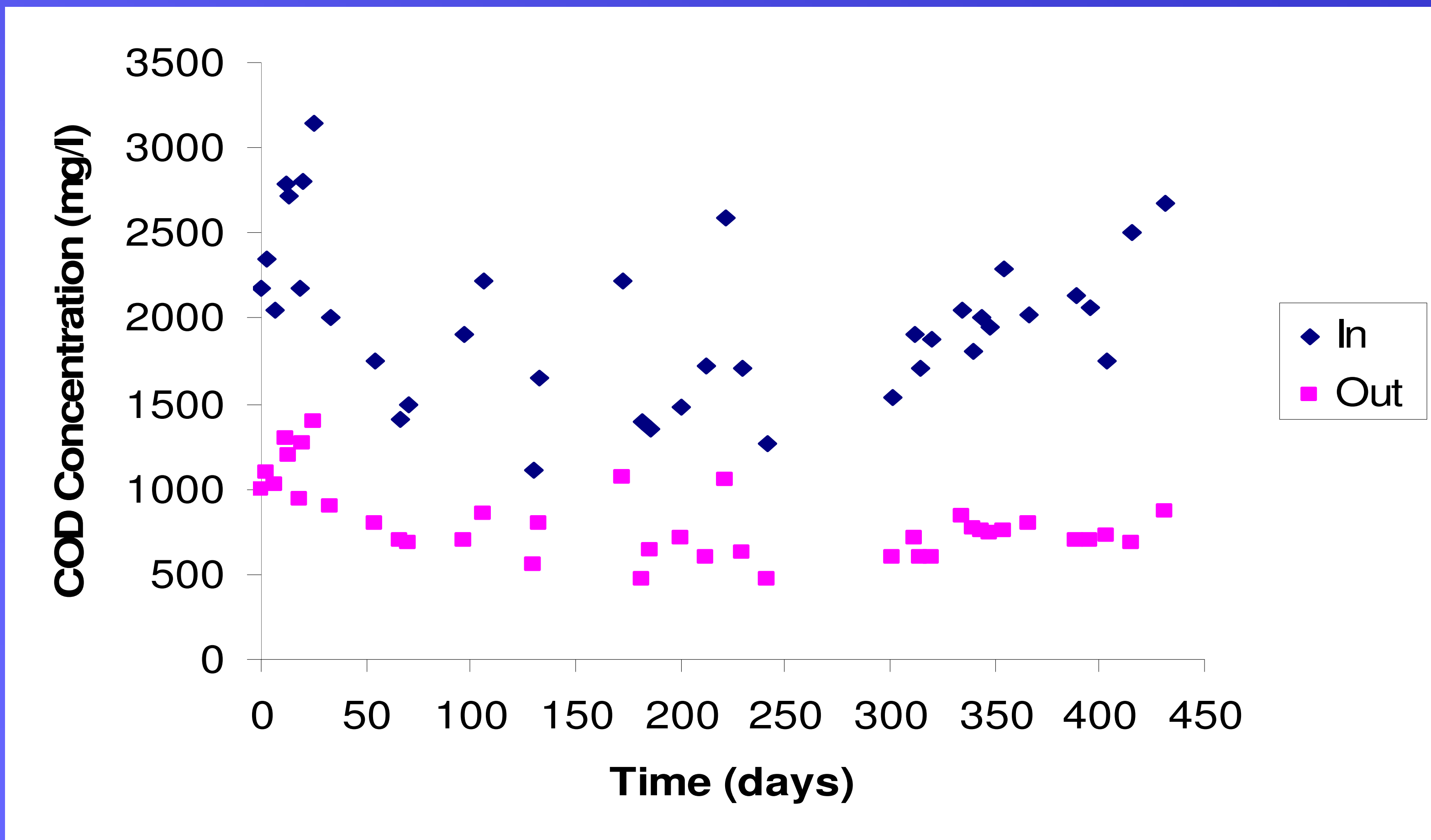
Typha latifolia
(cattail)

Typha latifolia (cattail)

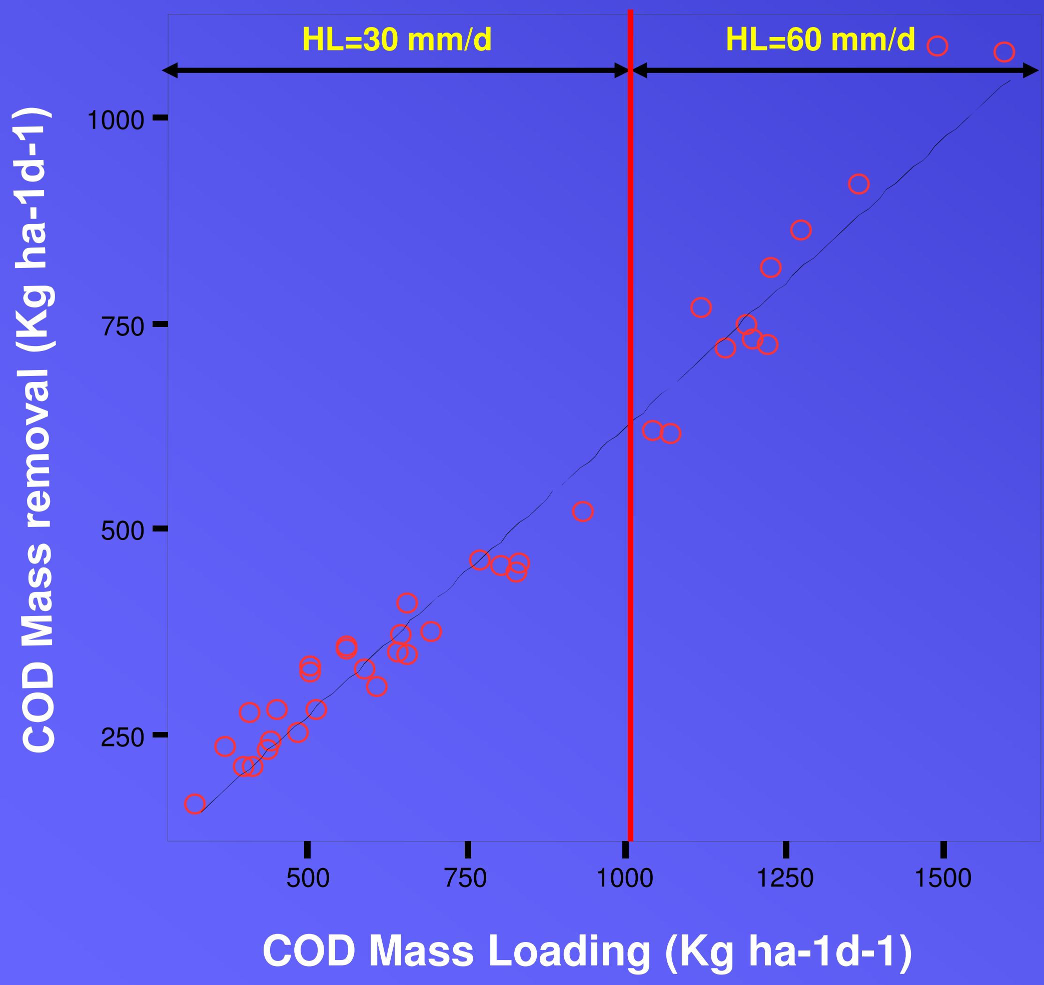
Iris pseudacorus

Phragmites australis
(common reed)

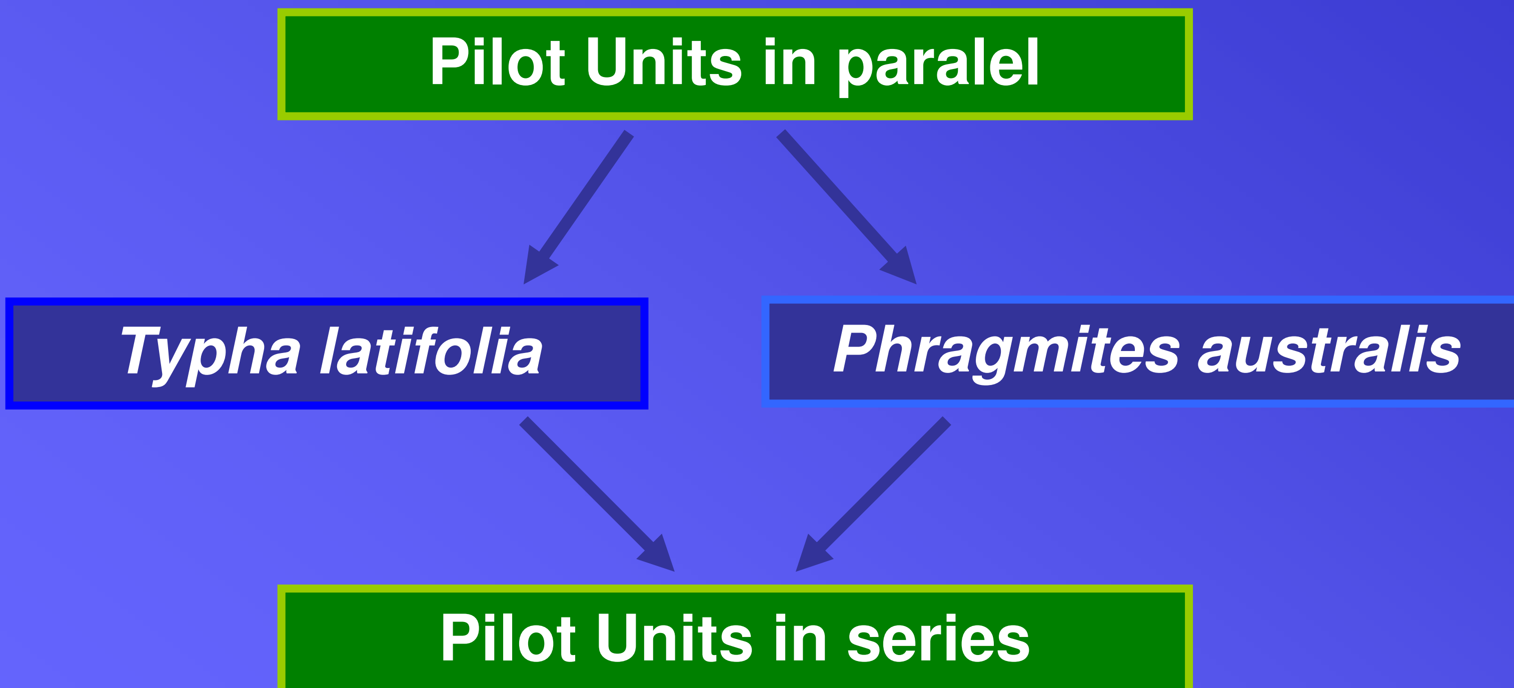
Efficiency of the pilot units - example



Removal efficency for organic loading



Pilot Units


Pilot Units in paralel
Typha latifolia
Phragmites australis
Pilot Units in series

Pilot Units – *Typha latifolia*

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Water characterization Series I

4 - 7 July 2005

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Hidraulic loading	60mm/d → 480 Kg $BOD_5 ha^{-1}d^{-1}$				
Parameters	In	Out 1		Out 2	
pH	6.57(8.46-5.25)	8.15(8.38-7.95)		8.11(8.25-7.90)	
COD, $mgO_2\ l^{-1}$	1297(1455-1091)	523(600-480)	59%	240(268-225)	54%
BOD_5, $mgO_2\ l^{-1}$	720 (800-660)	355 (390-320)	51%	175 (195-160)	51%
TSS, mg l^{-1}	35(43-26)	10(12-8)	72%	5 (6-4)	52%
Total P, mgP l^{-1}	0.66(0.95-0.26)	0.64(0.96-0.26)		0.62(0.82-0.27)	

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Water characterization Series I

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Hidraulic loading	180mm/d →	1700 $kgBOD_5ha^{-1}d^{-1}$			
Parameters	In	Out 1		Out 2	
pH	7.83(8.10-7.66)	8.23(8.65-8.09)		8.21(8.55-8.10)	
COD, mgO_2 l^{-1}	1579(2138-1082)	868(1200-570)	45%	595(840-380)	32%
BOD_5, mgO_2 l^{-1}	797(960-720)	570(670-520)	22%	446(523-410)	21%
TSS, mg l^{-1}	54(63-42)	12(14-9)	78%	4(4-3)	66%
Total P, mgP l^{-1}	0.24(0.30-0.15)	0.24(0.32-0.17)		0.27(0.40-0.16)	

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Pilot Units - *Phragmites australis*

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Water characterization Series II

Hidraulic loading	60mm/d → 480 Kg BOD_5 $ha^{-1}d^{-1}$				
Parameters	In	Out 1		Out 2	
pH	6.57(8.46-5.25)	7.94(8.33-5.84)		8.17(8.38-7.99)	
COD, mgO_2 l^{-1}	1297(1455-1091)	530(590-500)	59%	249(265-235)	53%
BOD_5, mgO_2 l^{-1}	720 (800-660)	363(400-333)	50%	181(200-160)	50%
TSS, mg l^{-1}	35(43-26)	10(13-7)	71%	6(6-5)	52%
Total P, mgP l^{-1}	0.66(0.95-0.26)	0.62(0.86-0.25)		0.58(0.72-0.27)	

Water characterization Series II

4 - 7 July 2005

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Hidraulic loading	180mm/d → 1700 kg BOD_5 $ha^{-1}d^{-1}$				
Parameters	In	Out 1		Out 2	
pH	7.83(8.10-7.66)	8.19(8.54-8.06)		8.25(8.61-8.07)	
COD, mgO_2 l^{-1}	1579(2138-1082)	905(1189-650)	42%	628(820-450)	31%
BOD_5, mgO_2 l^{-1}	797(960-720)	578(700-530)	27%	456(550-412)	21%
TSS, mg l^{-1}	54(63-42)	11(15-8)	80%	4(5-3)	65%
Total P, mgP l^{-1}	0.24(0.30-0.15)	0.30(0.46-0.18)		0.25(0.32-0.20)	

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3 Instalação dos leitos

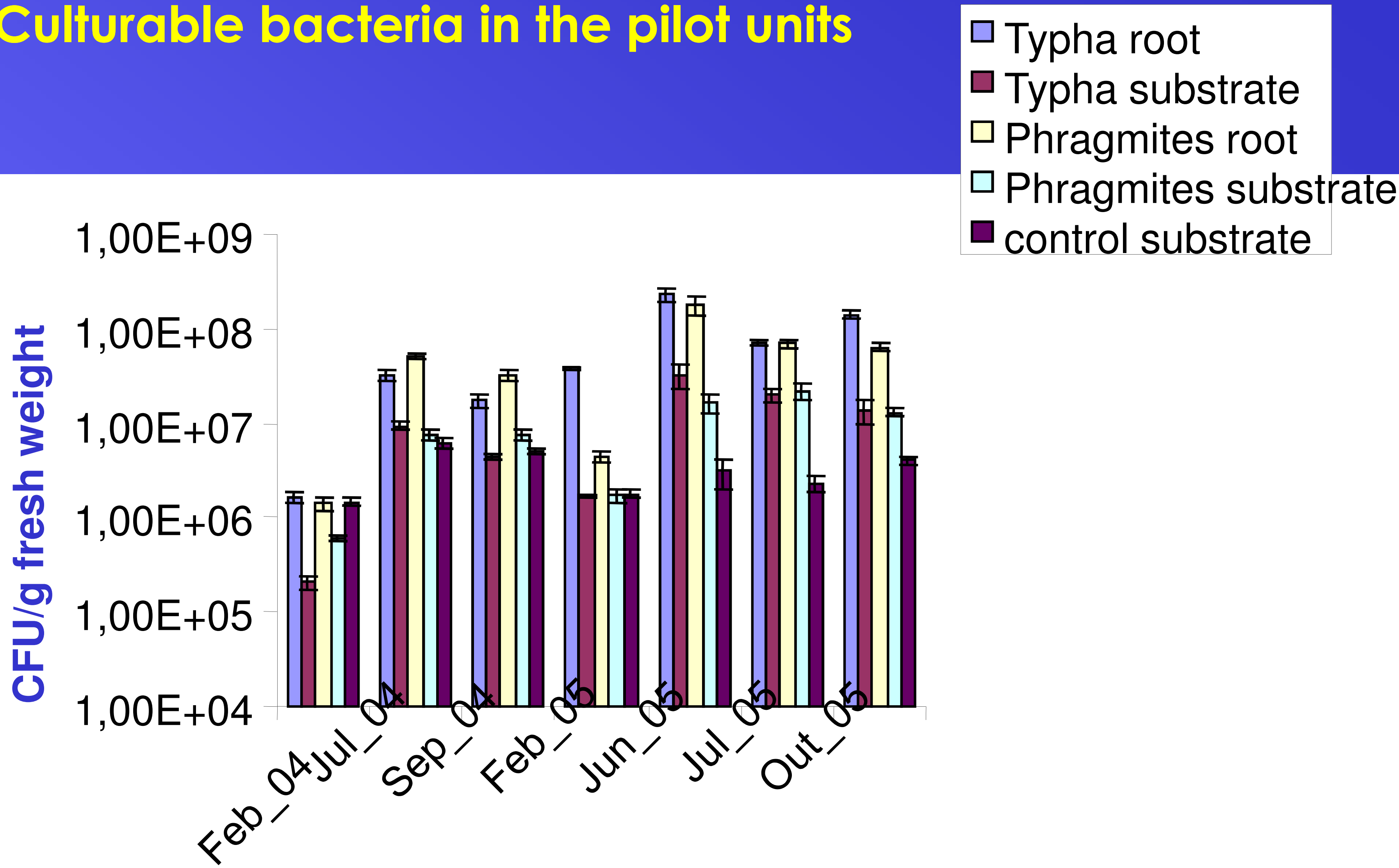
	unidades piloto: *Typha latifolia*		
Carga hidraulica	**Entrada (Kg/had)**	**saida U1**	**saida U2**
180mm/d	3800-1950	48-41%	33-30%
60mm/d	870-650	66-52%	60-50%

3 Instalação dos leitos

	unidades piloto: *Phragmites australis*		
Carga hidraulica	**Entrada (Kg/had) Conc**	**Conc saida U1**	**Conc saida U2**
180mm/d	3800-1950	(47-39%)	(32-29%)
60mm/d	870-650	(64-52%)	(56-50%)

Filtralite MR
Typha
Typha
Phragmites

Culturable bacteria in the pilot units



DGGE analysis is underway

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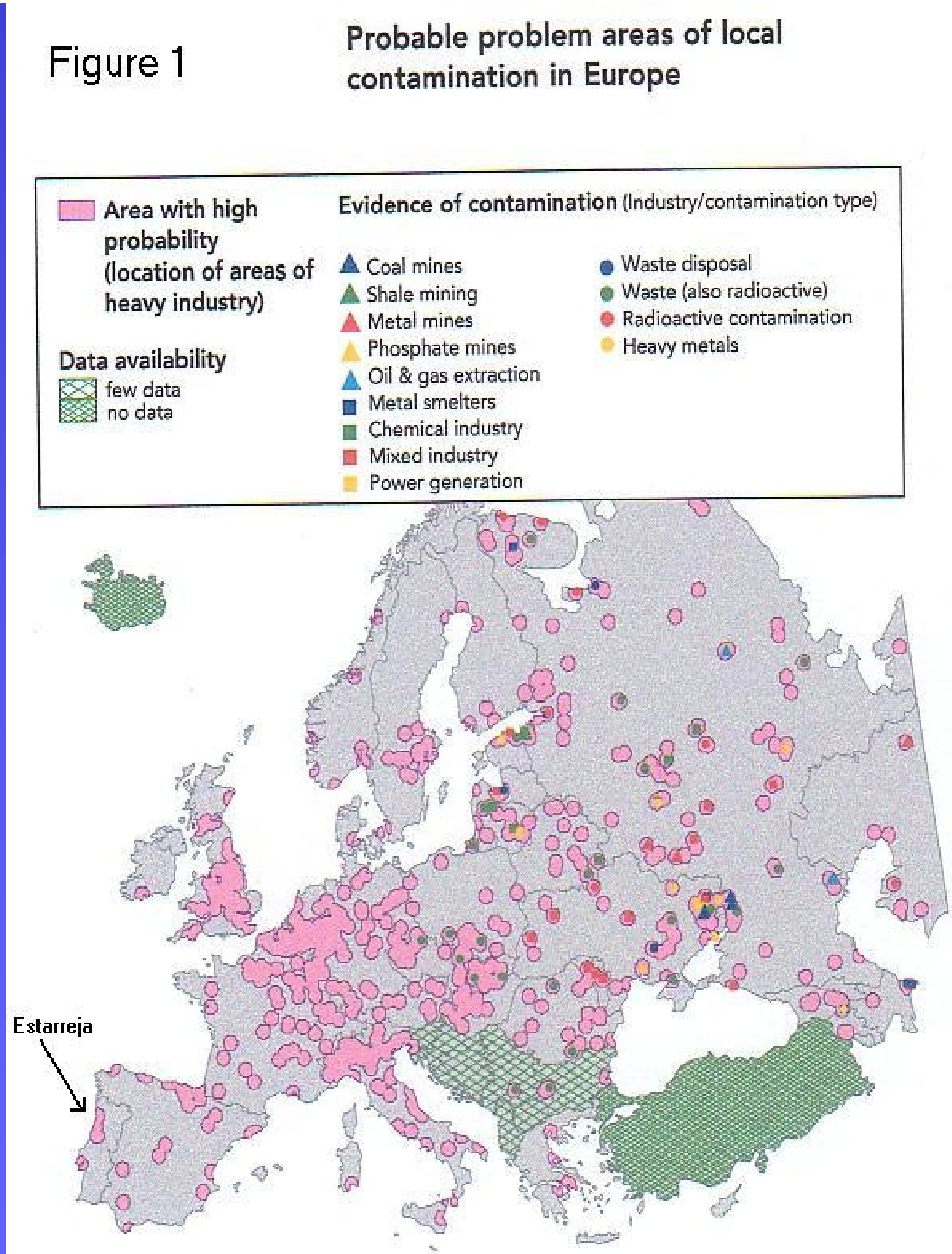
Estarreja –

Industrial site

Cerca de 2 mil milhões ha de solo sofrem de degradação antropogénica na Europa e a recuperação de solos degradados pode tornar-se a "prioridade do século para a sustentabilidade"



Industrial sediment

- Acetylene and PVC production
- $Ca(OH)_2$ residues
- 300 000 ton, 10 ha
- High pH (11.8-12.6) and salinity
- Low nutrient levels (ex. N e P)

Scarce vegetation and limited plant diversity

Phytorestoration

Phyto-microbial complexes

Phytotechniques

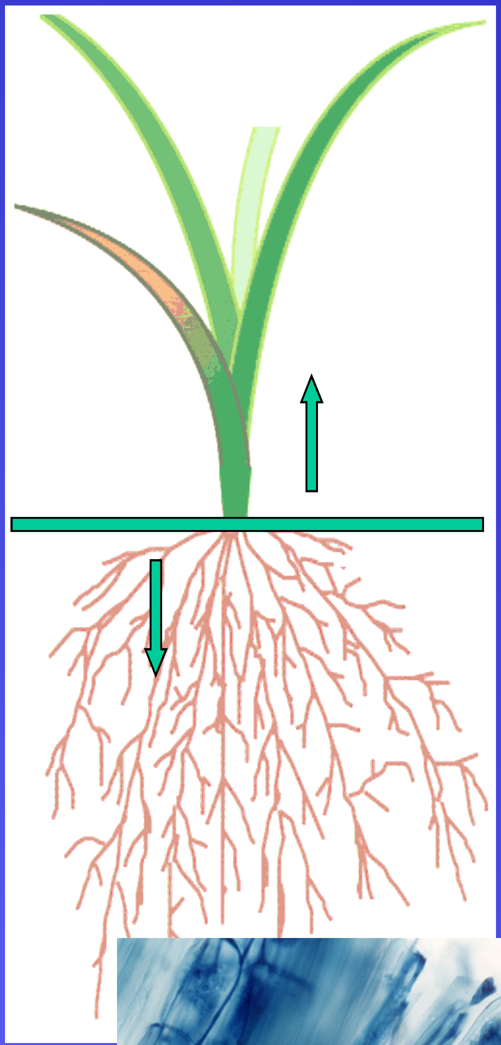
Plants have to grow under stress....

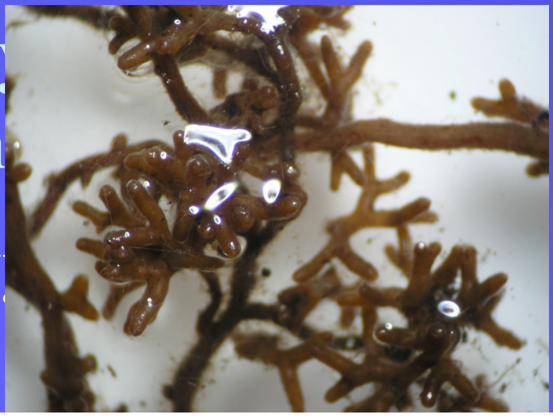
↓

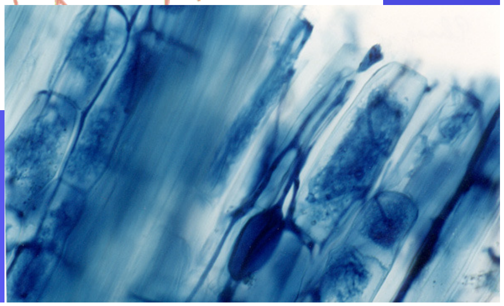
Symbiosis between adapted plants, bacteria and fungi…

Mycorrhizal fungi are crucial components

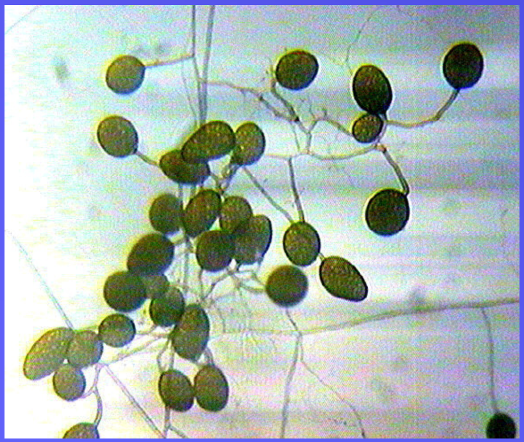
- Group of soil microorganisms
- Form symbiotic associations with plants roots
- Improve plant growth and reproduction
- Capture mineral nutrients from soil
- Receive carbohy associated plan
- Influence heav

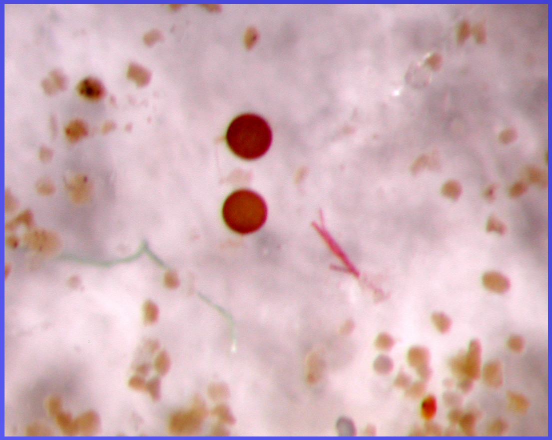






Survey and isolation of arbuscular mycorrhizal fungi

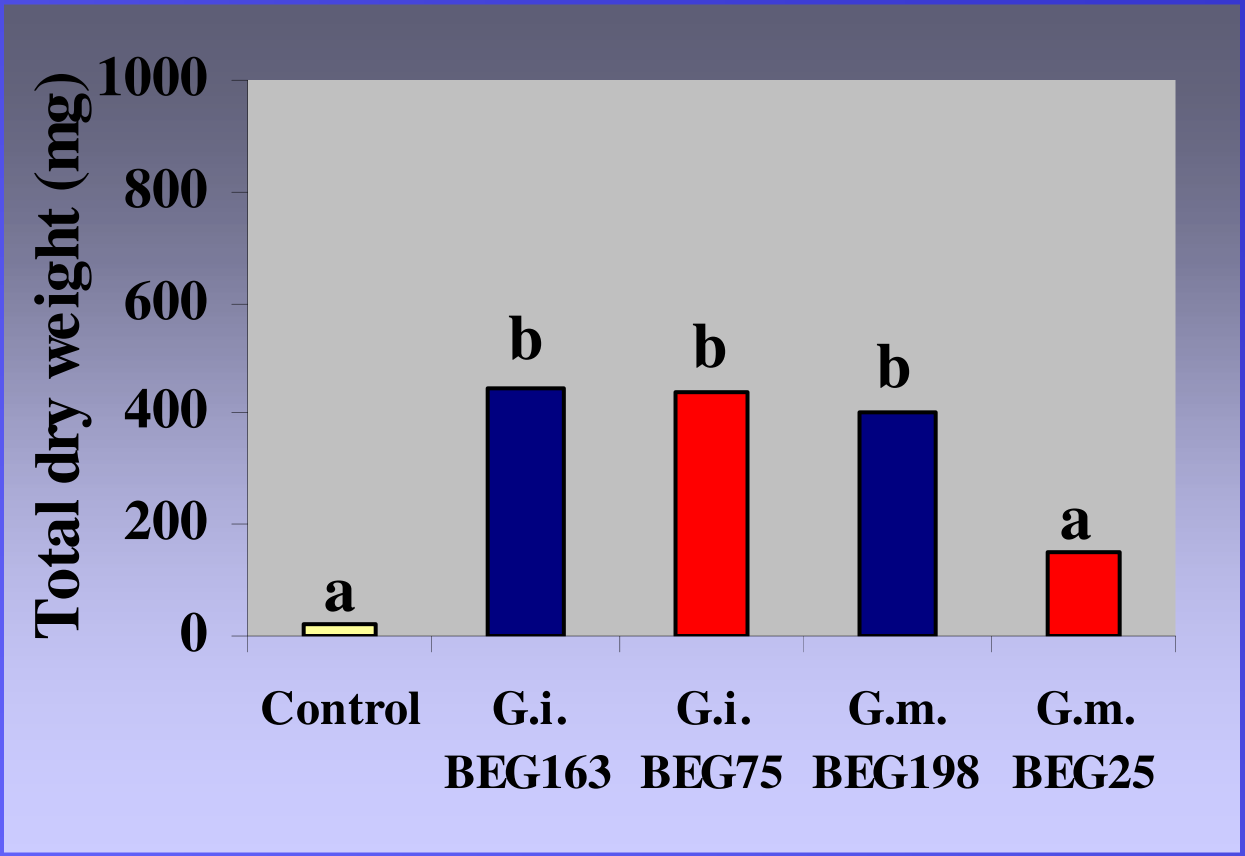




Glomus intraradices *Glomus* geosporum

Study of the effect of native and non-native AMF on plant establishment in the industrial sediment

Inoculated with native and non-native *G. intraradices* and *G. geosporum*

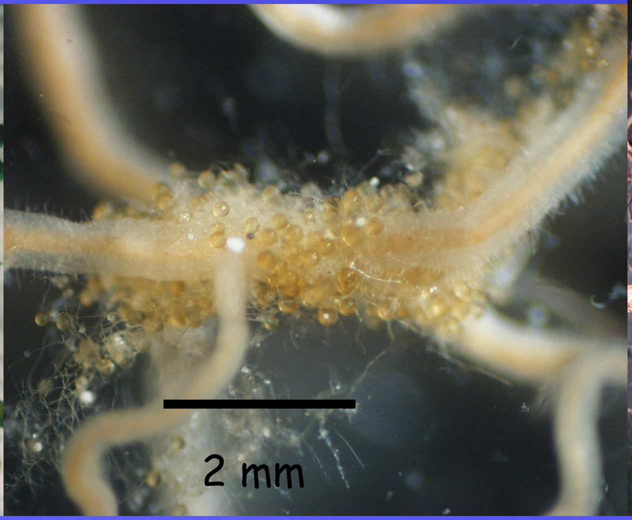


AMF play a critical role in the growth and establishment of native plant species (ex. *Conyza bilbaoana)*

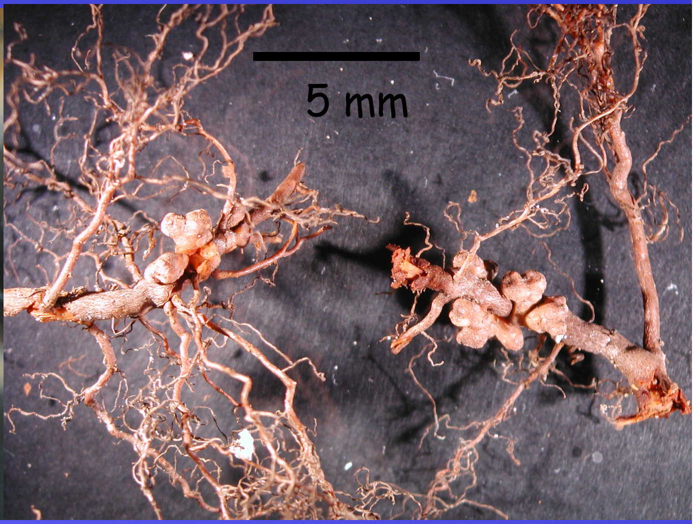
The use of adapted AMF as inoculants is recommended for the phytorestoration of the highly alkaline anthropogenic sediment

Study of the effect of AMF and bacteria on plant establishment in the industrial sediment

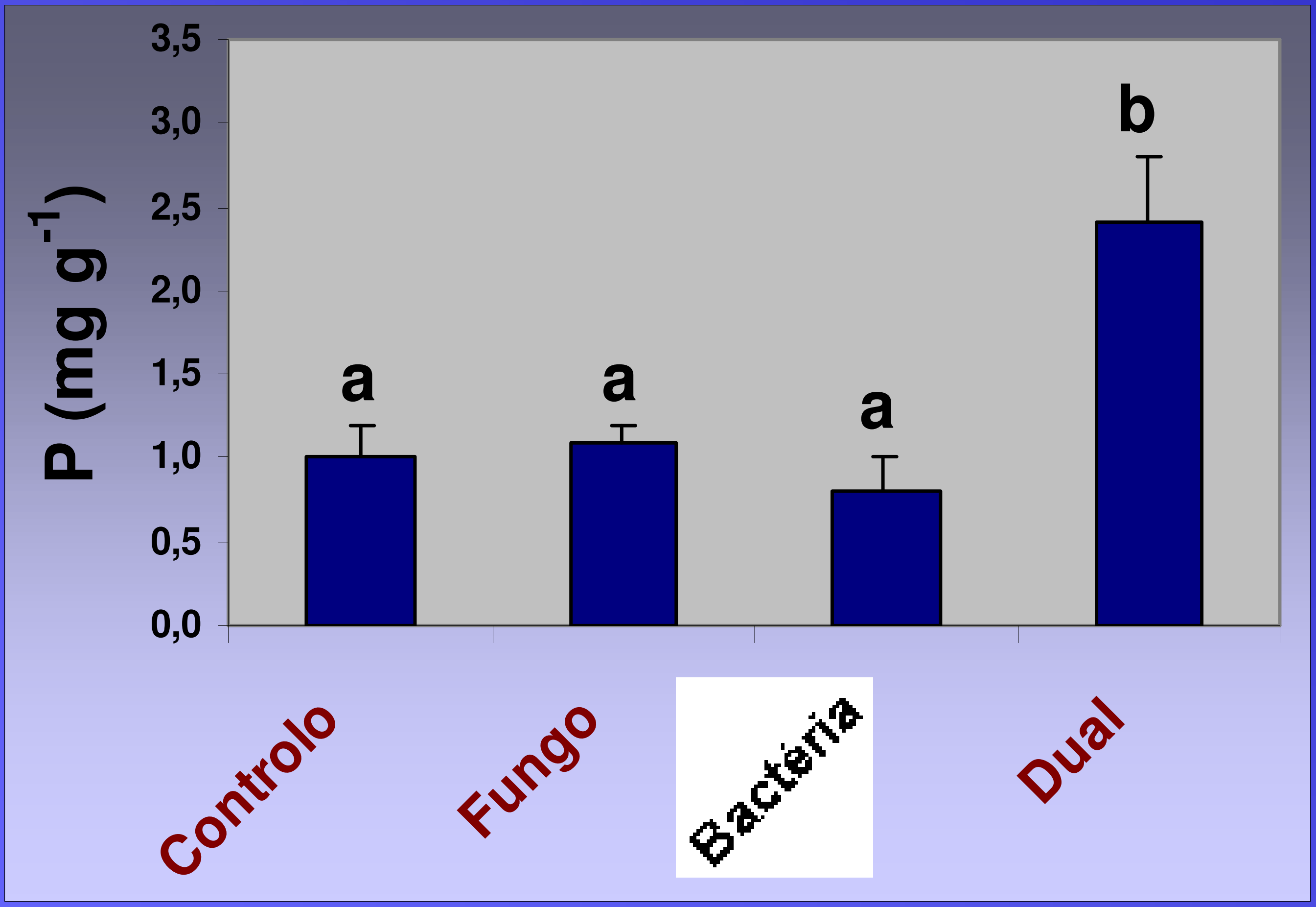
Alnus glutinosa



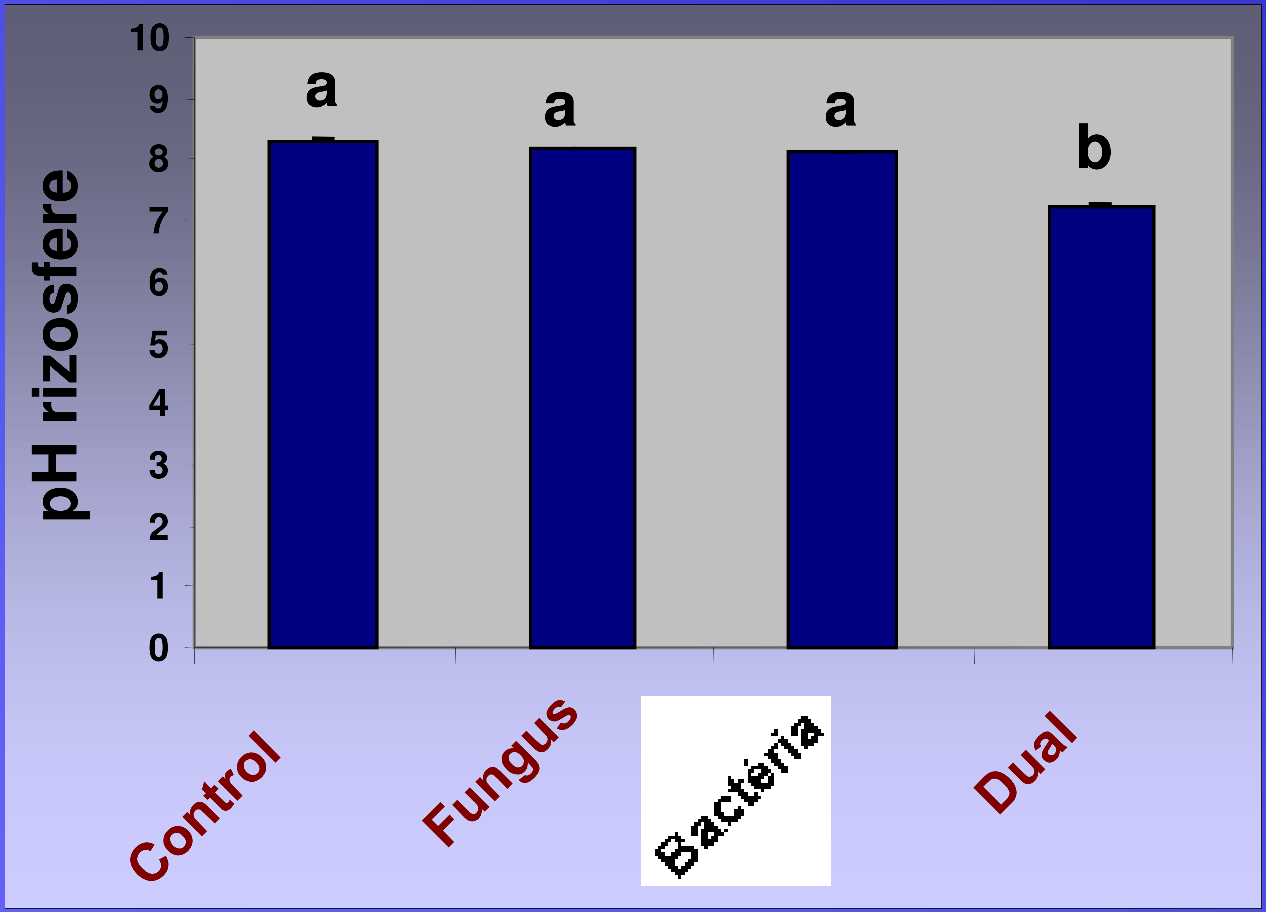
Glomus intraradices



Frankia sp.



Synergistic effect between AMF and nitrogen fixing bacteria (*Frankia*) led to improved plant benefit in phosphorus nutrition



Synergistic effect between AMF and nitrogen fixing bacteria (*Frankia*) led to an aliviation of high pH stress by reducing rizosphere pH

Long-term field trial on-going

Plants still growing on the site

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Heavy metal contaminated soil

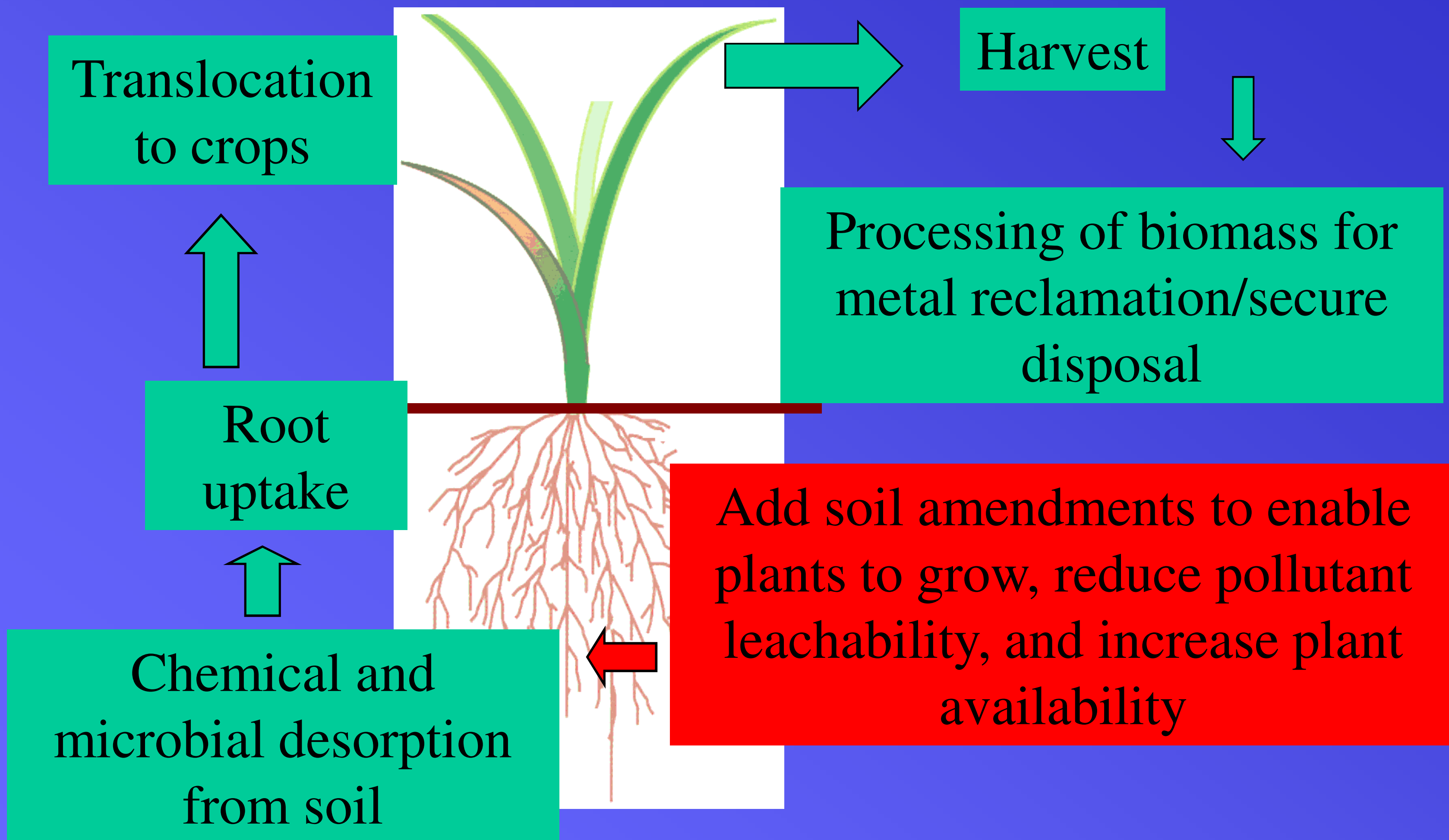
- Discharge of solid residues in the surrounding area
- Conducting of industrial wastewaters into a stream nearby (“Esteiro de Estarreja”)

Total metal in the banks (mg/ Kg soil)

Zn	898.9 (125-3620)
Pb	835.4 (16-3740)
Hg	66.6 (0.3-275)
As	1495 (45-5620)

Levels higher than European legislation

Plant based decontamination of Metal-contaminated soils



Factors to take in account

Plant

- Rapid growth
- High biomass rate
- Capacity to tolerate and accumulate the contaminant
- Adequate root length
- Adequate to the nature of the contamination

Contaminant

- Bioavailability of the contaminant
- Existence of multiple contamination

Survey of local plants

Rubus ulmifolius

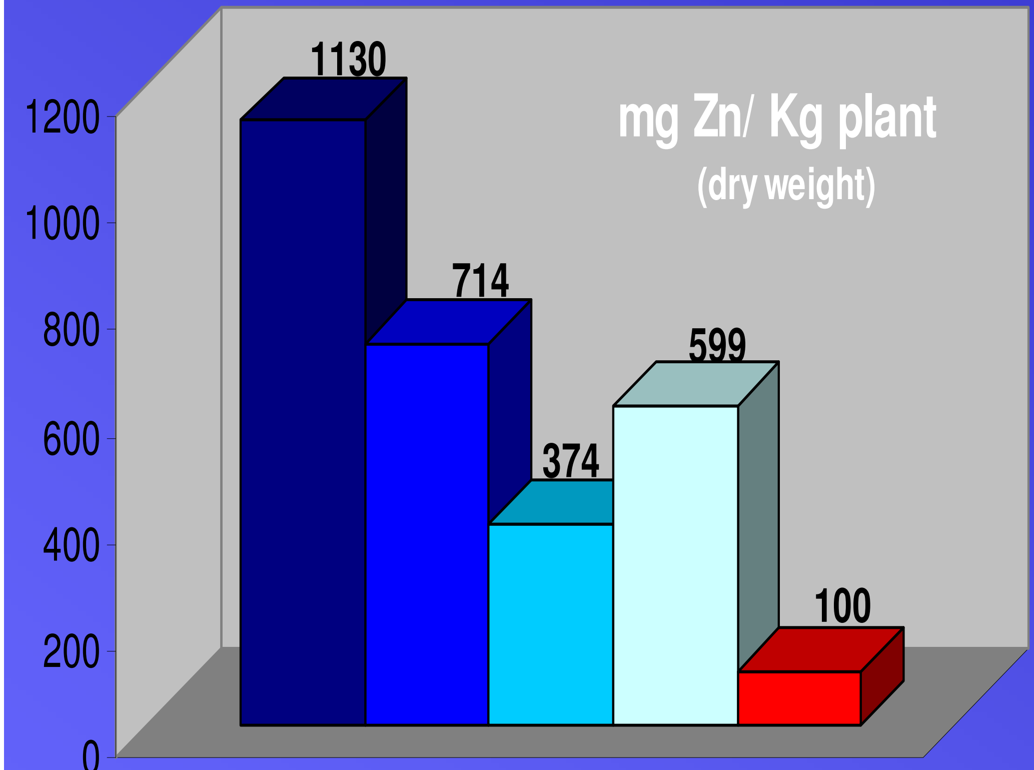
***Convolvulus* sp.**

Phragmites australis

Solanum nigrum

Levels of elements in the plants

Metal / Plant	Lead (mg/Kg dry weight)	Zinc (mg/Kg dry weight)	Arsenic (mg/Kg dry weight)	Mercury (mg/Kg dry weight)
Solanum nigrum	2.6	**1130**	5.4	9.1
Rubus ulmifolius	6.0	**714**	31.2	0.5
Phragmites australis	2.7	**374**	2.9	12.7
Convolvulus sp.	2.8	**599**	2.3	1.6



	Zn
Solanum nigrum	1130
Rubus sp.	714
Phragmites australis	374
Convolvulus sp.	599
Average maximum levels in plants not submited to contamination	100

- Zn -

- High levels of **Zn** were detected in all the plants, especially on *Solanum nigrum*,

Growth experiments with *Solanum nigrum* exposed to several Zn levels and different mycorrhizal fungi

Zn= 0 ppm matrix=sand					
fungus A	fungus B	fungus C	fungus D	fungus E	No fungi

Zn= 100 ppm matrix=sand					
fungus A	fungus B	fungus C	fungus D	fungus E	No fungi

Zn= 500 ppm matrix=sand					
fungus A	fungus B	fungus C	fungus D	fungus E	No fungi

Zn= 1000 ppm matrix=sand					
fungus A	fungus B	fungus C	fungus D	fungus E	No fungi

Soil from the banks of "Esteiro de Estarreja" (426± 2 ppm)					
fungus A	fungus B	fungus C	fungus D	fungus E	No fungi

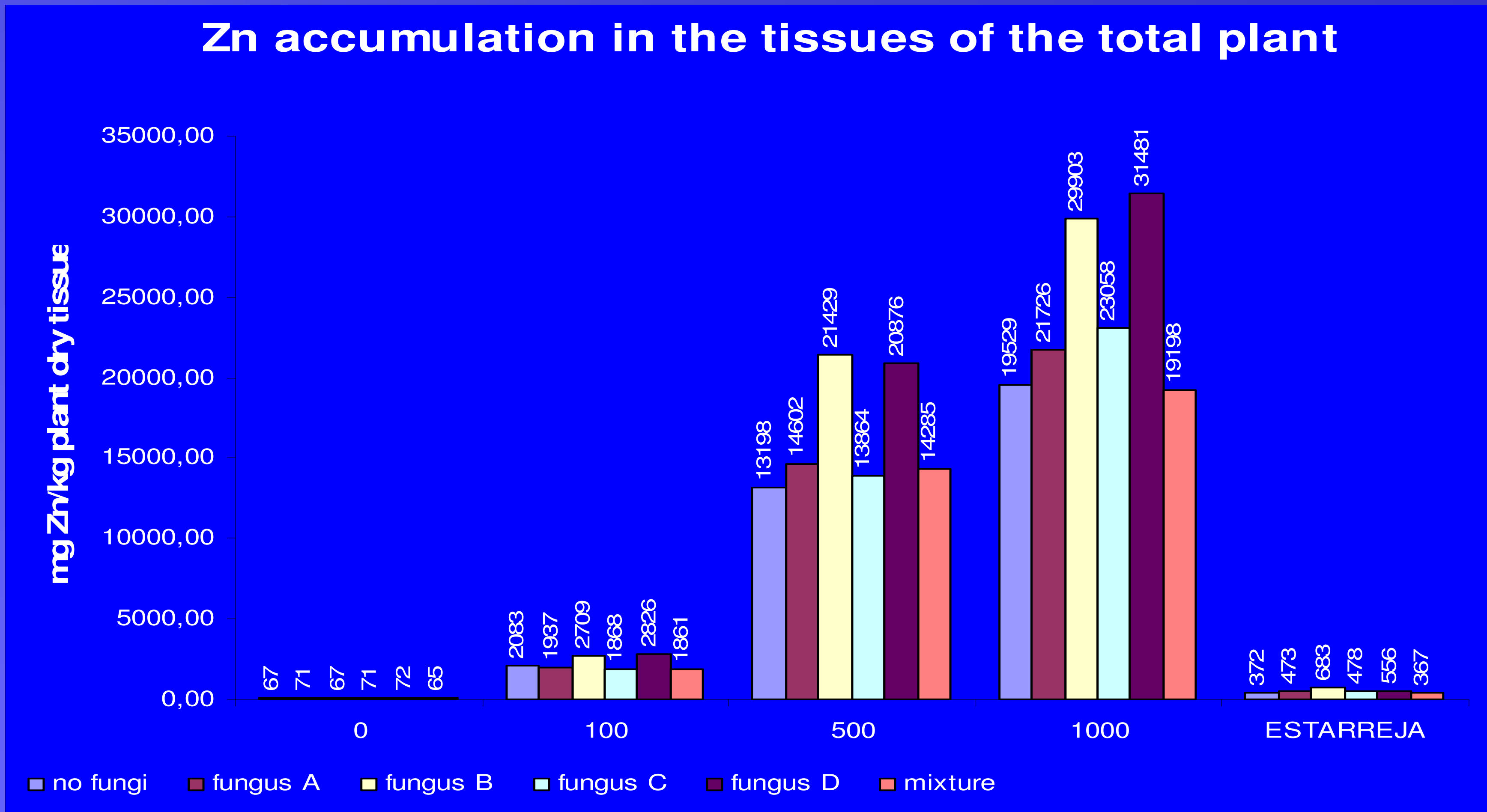
fungus A - *Glomus* sp. BEG140
isolated from a soil with high levels of Mn

fungus B - *Glomus claroideum*
isolated from a soil with high levels of Cd and Zn

fungus C - *Glomus mosseae*
isolated from a soil with high levels of Cd and Zn

fungus D - *Glomus intraradices*
isolated from a soil with high levels of Pb

fungus E= mixture of all the isolates



- Inoculation with *G. claroideum* and *G. intraradices*, enhanced zinc accumulation in *S. nigrum.*
- The stem tissues had the higher Zn content, followed by the roots, with the leaves registering the lowest values.

Zinc level in the matrix	Percent increase in the Zn accumulation levels in the tissues (%)	
	Glomus claroideum	*Glomus intraradices*
100	30	36
500	62	58
1000	53	61
Estarreja	83	49

The application of *S. nigrum* with the assistance of the AMF *G. claroideum* and *G. intraradices* in the phytoremediation of contaminated soil from "Esteiro de Estarreja" is currently being tested in different conditions:

- amendment with quelating agents (EDTA and EDDS)

- amendment with organic matter sources (manure and sludges from wastewater treatment)

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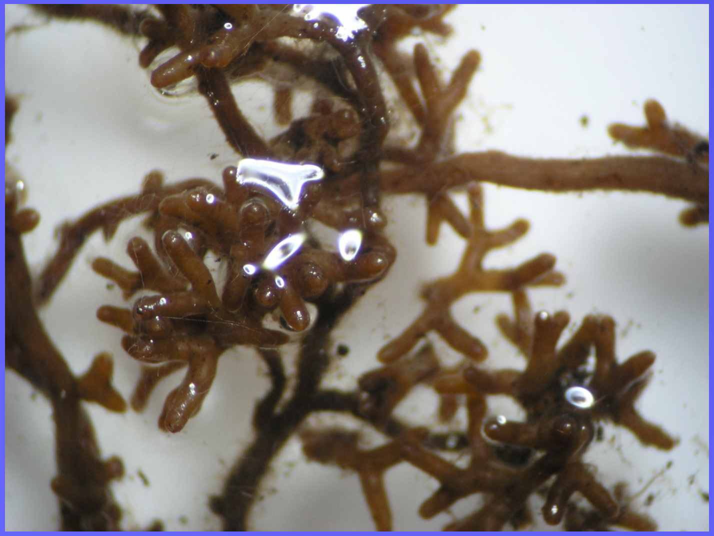
Sustainable plant production in forestry

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