# The use of organic and inorganic amendments in the phytoremediation of contaminated soils and their effect on biodiversity

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*Biodiversity and bioindicators in monitoring and management of contaminated soils*

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CSIC Consejo Superior de Investigaciones Científicas
CEBAS Centro de Edafología y Biología Aplicada del Segura

# Trace elements - Contamination - Phytoremediation

TRACE ELEMENT CONTAMINATED SOILS

Metals (Cd, Cu, Pb, Zn, etc.) & metalloids (As, Sb, etc.)

Options for soil toxicity reduction

Environmental Risk Assessment

Risk-based Remediation


# Remediation methods for contaminated soils

**Physico-chemical methods**

- Separation and extraction
  - Mechanical separatio
  - Pyrometallurgi
  - Electroki
- Isolation
  - /Horizontal barriers
  - acro-, micro-encapsulation
- Inme
  - Solidification
  - Stabilization
  - Vitrification
- icity reduction
  - Adsorption
  - Ionic exchange
  - Physico-chemical washing

**Damage to soil functionality**

**Biological methods**

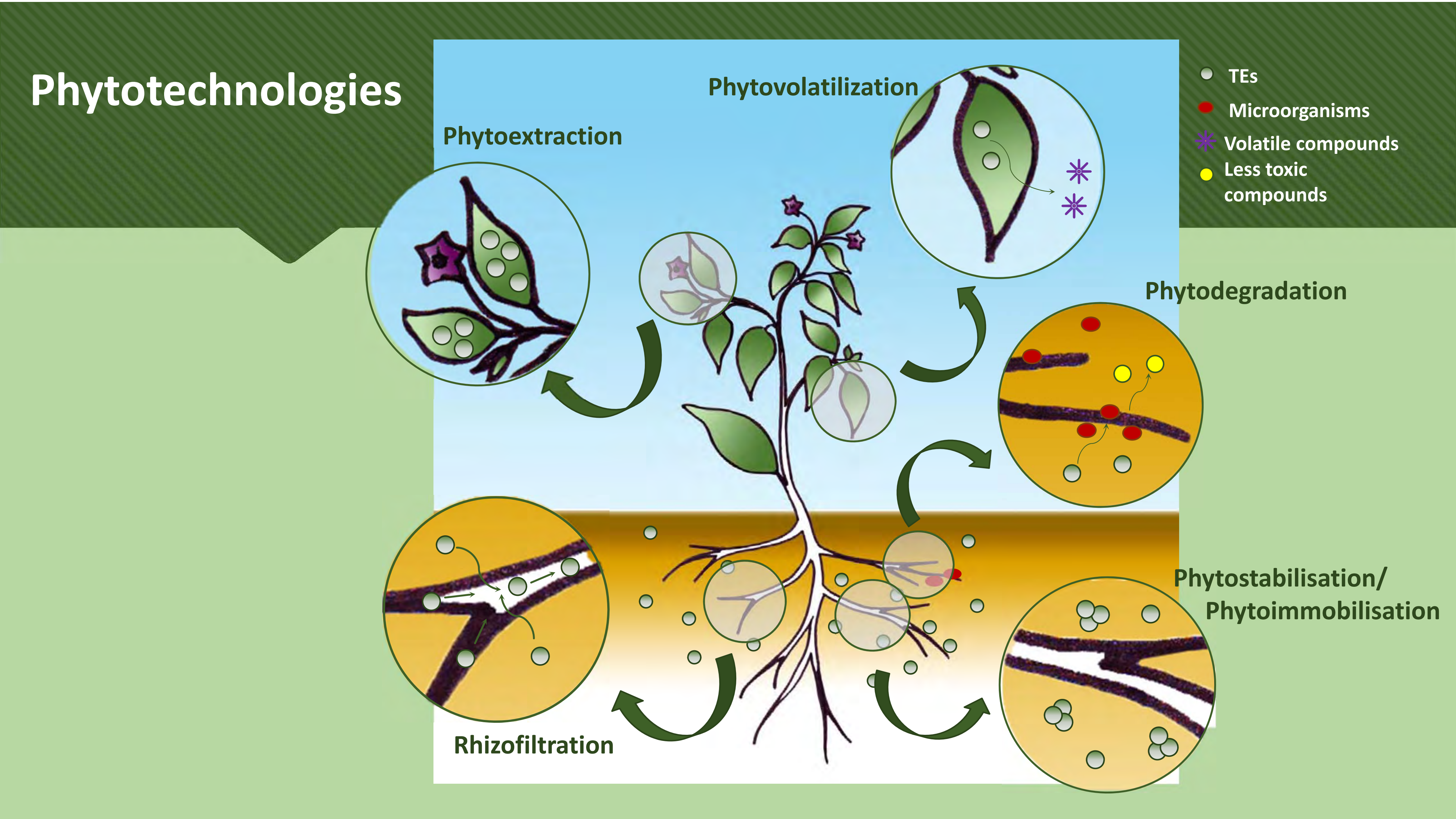
Bioremediation / Biorestoration

***Natural processes/attenuation***

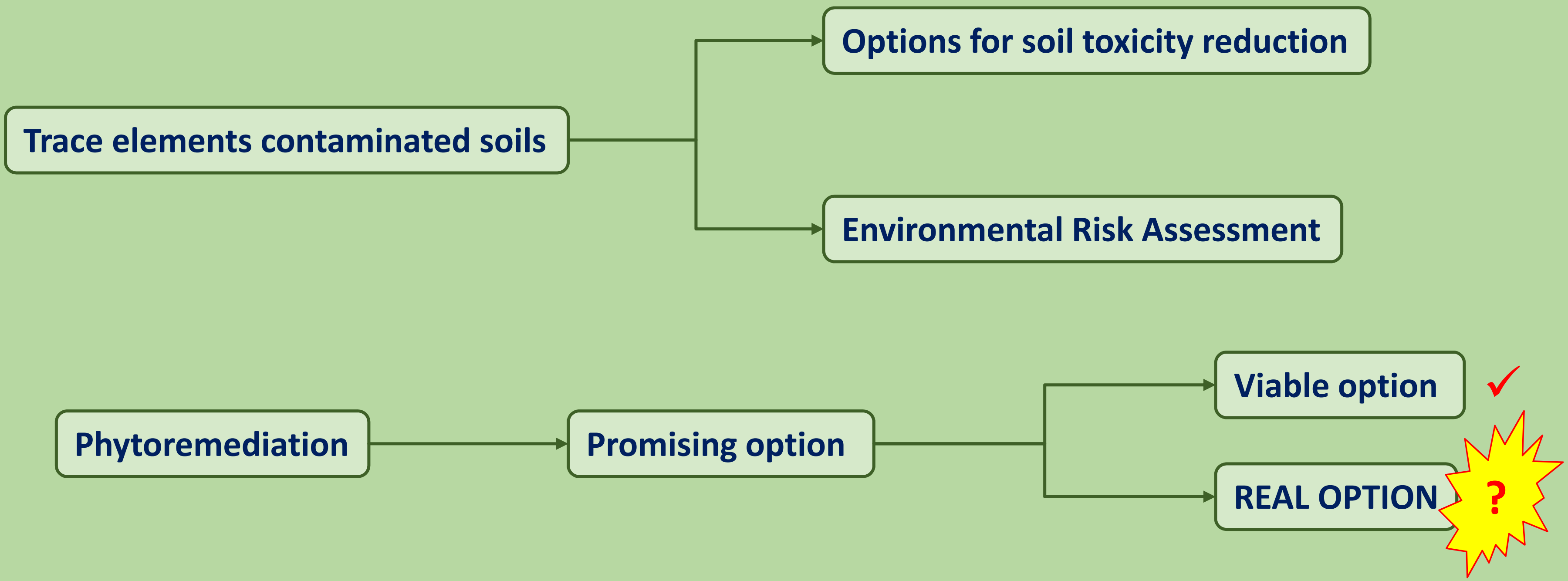
***SOIL HEALTH***

- Microorganisms
- Higher plants → **Phytoremediation**

"techniques based on the use of plant species (and their associated microorganisms), **amendments** and agronomical techniques to eliminate, retain or diminish the toxicity of the contaminants" (Salt et a., 1998; Mench et al., 2009)


Phytotechnologies
Phytoextraction
Phytovolatilization
TEs
Microorganisms
Volatile compounds
Less toxic compounds
Phytodegradation
Phytostabilisation/
Phytoimmobilisation
Rhizofiltration

# Trace elements - Contamination - Phytoremediation



# Trace elements - Contamination - Phytoremediation

**MAJOR CHALLENGES**

1. **Conditioning of the soils**
    - **Acidity/alkalinity, fertility, structure**
2. **Plant survival & growth: species selection**
    - **Tolerance, adapted, accumulation/exclusion**
3. **Monitoring and assessment**
    - **Eco-toxicity, bioindicators, ecosystem services**
4. **Management of the generated biomass**
    - **Valorization options**

# Conditioning of the soils

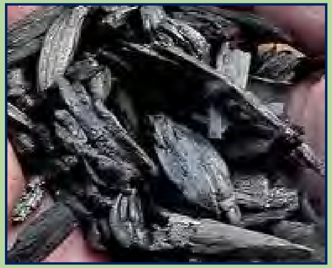
**Soil amelioration and conditioning**

- Waste materials: organic and inorganic → Recycling & reutilization → End of waste / Circular economy
- Amendments selection: crucial → Allow/Improve plants growth / TEs solubility, mobility, speciation & bioavailability
- Immobilization → ↓ solubility/availability → Combination of amendments
- Extraction → ↑ solubility/availability → Acid, fresh/redox active

# Conditioning of the soils

**ORGANIC AMENDMENTS**

- ✓ Sewage sludge
- ✓ Municipal waste
- ✓ Manure
- ✓ Compost
- ✓ Agri-food byproducts
- ✓ Biochar
- ✓ Digestate



**INORGANIC AMENDMENTS**

- ✓ Lime
- ✓ Zeolites
- ✓ Fe rich materials
- ✓ Nanoparticles
- ✓ Red mud
- ✓ Other residues (paper mill)

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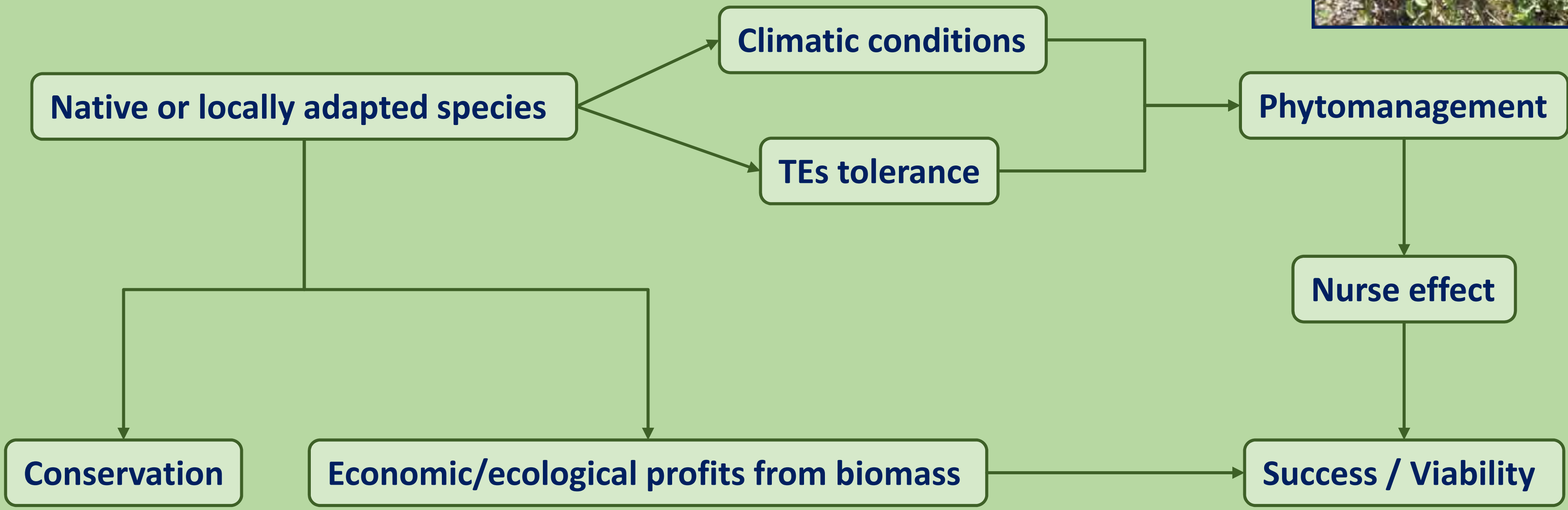
# Selection of the plants



# Selection of the plants: extraction vs stabilisation

***Pteris vittata* L.** (As accumulator; Cao et al., 2003)

***Nocaea caerulesens*** (Cd & Zn hyperaccumulator; Baker et al., 1994)

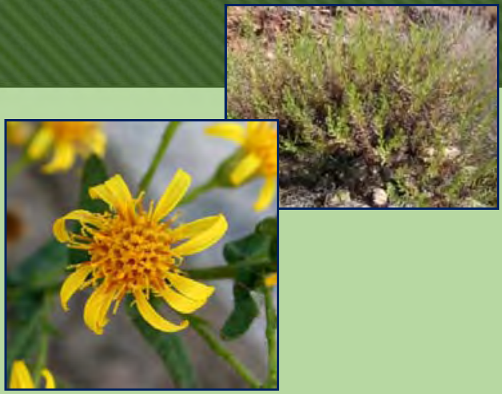
***Alyssum murale*** (Ni & Cd phytomining; Chaney et al., 1999)

***Agrostis capilaris, Festuca rubra*** (Vangronsveld et al., 1998)

**Soya, rapeseed, sunflower, sorghum, common cane** (economic revenue)

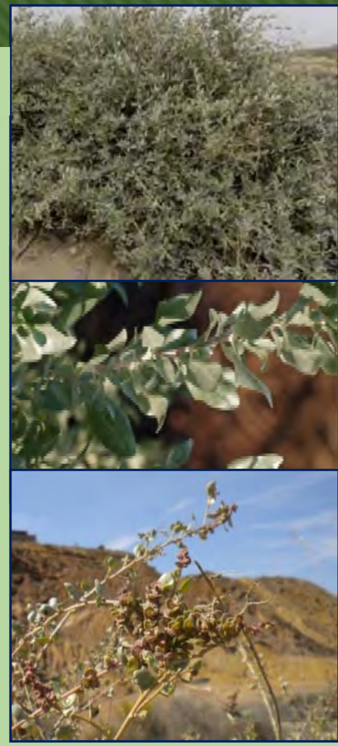
***Salix spp.* (willow) y *Populus spp.* (poplar)** (high biomass, fast growth, energy crops)

# Selection of the plants: native/adapted species

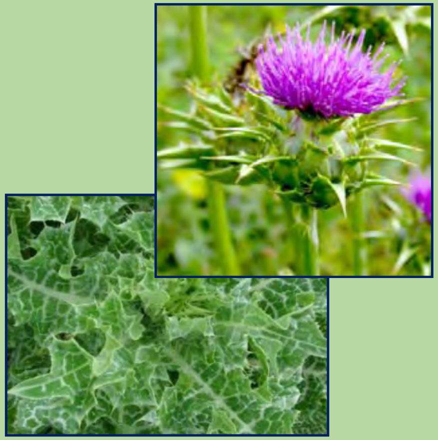


***Dittrichia viscosa*** **(L.) Greuter**

***Atriplex halimus*** **(L.)**



***Sylibum marianum (L.)*** **Gaertn**



***Piptatherum miliaceum*** **(L.) Cosson**

***Nicotiana glauca*** **Graham**

***Bituminaria bituminosa (L.)*** **Stirton**

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# Monitoring and assessment

**SOIL HEALTH**

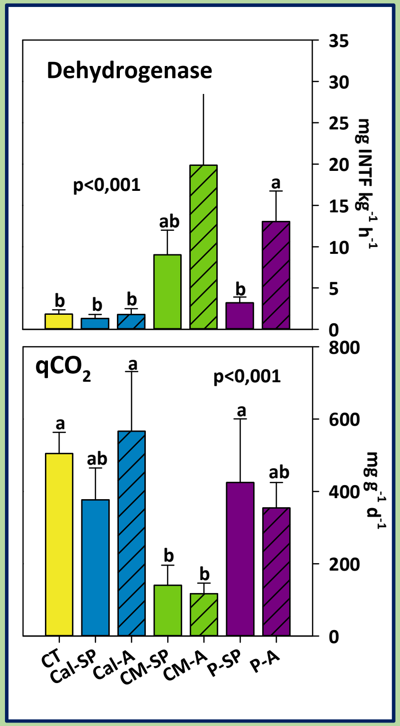
Indicators to monitor soil restoration:

- Trace elements solubility
- Soil solution (pore water)
- Accumulation in the plants

Bio-indicators (microbial parameters):

✓ Microbial community size ($CO_2$-C, Biomass-C, $qCO_2$)

✓ Biological functionality, general activity and functional diversity (enzymatic activities, FDA, CLPPs, etc.)

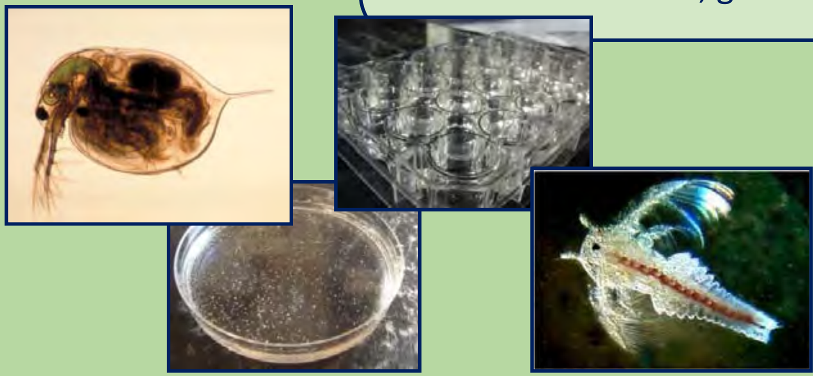


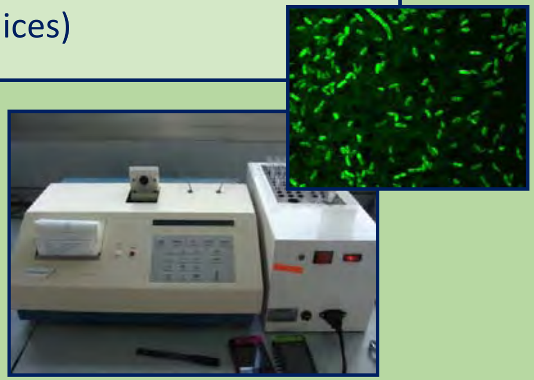
# Monitoring and assessment

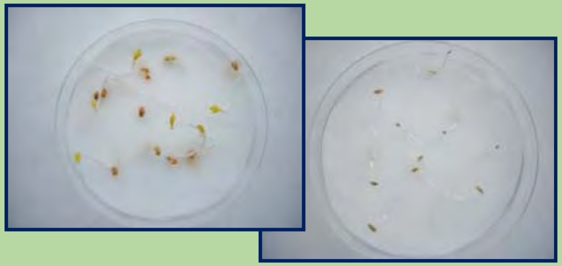
**SOIL HEALTH**

Eco-toxicity Tests (bio-assays):

- ✓ Direct (earthworms (*Eisenia fetida*) mortality, plant growth test)
- ✓ Indirect (*Vibrio fischeri* luminescence inhibition, *Daphnia magna*/*Thamnocephalus platyurus* immobilization, germination indices)







# Trace elements - Contamination - Phytoremediation

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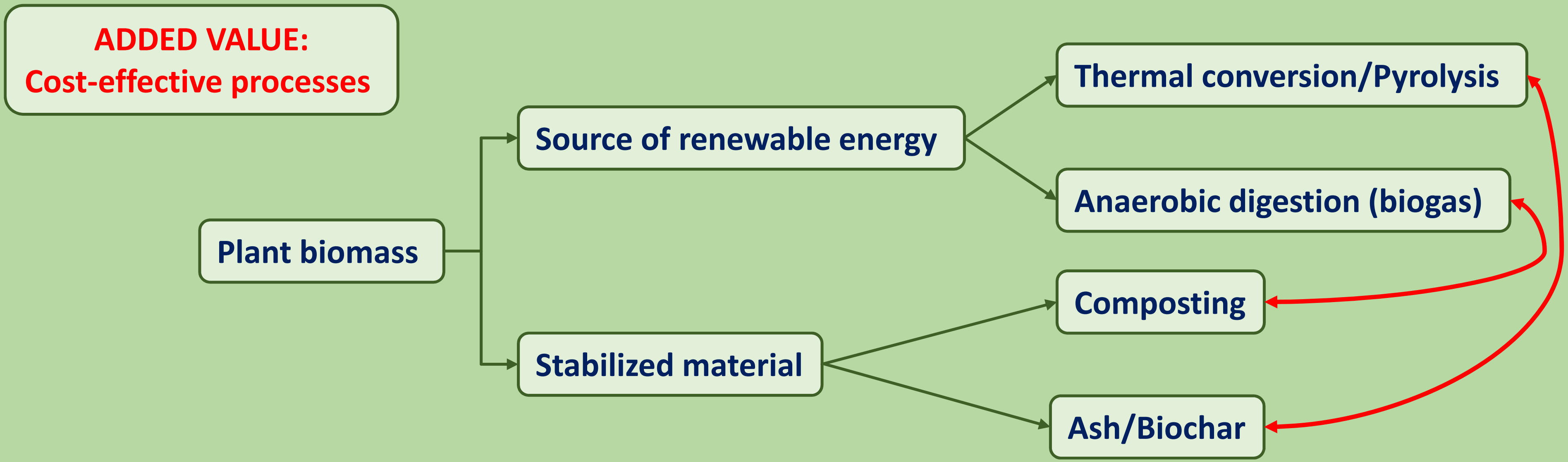
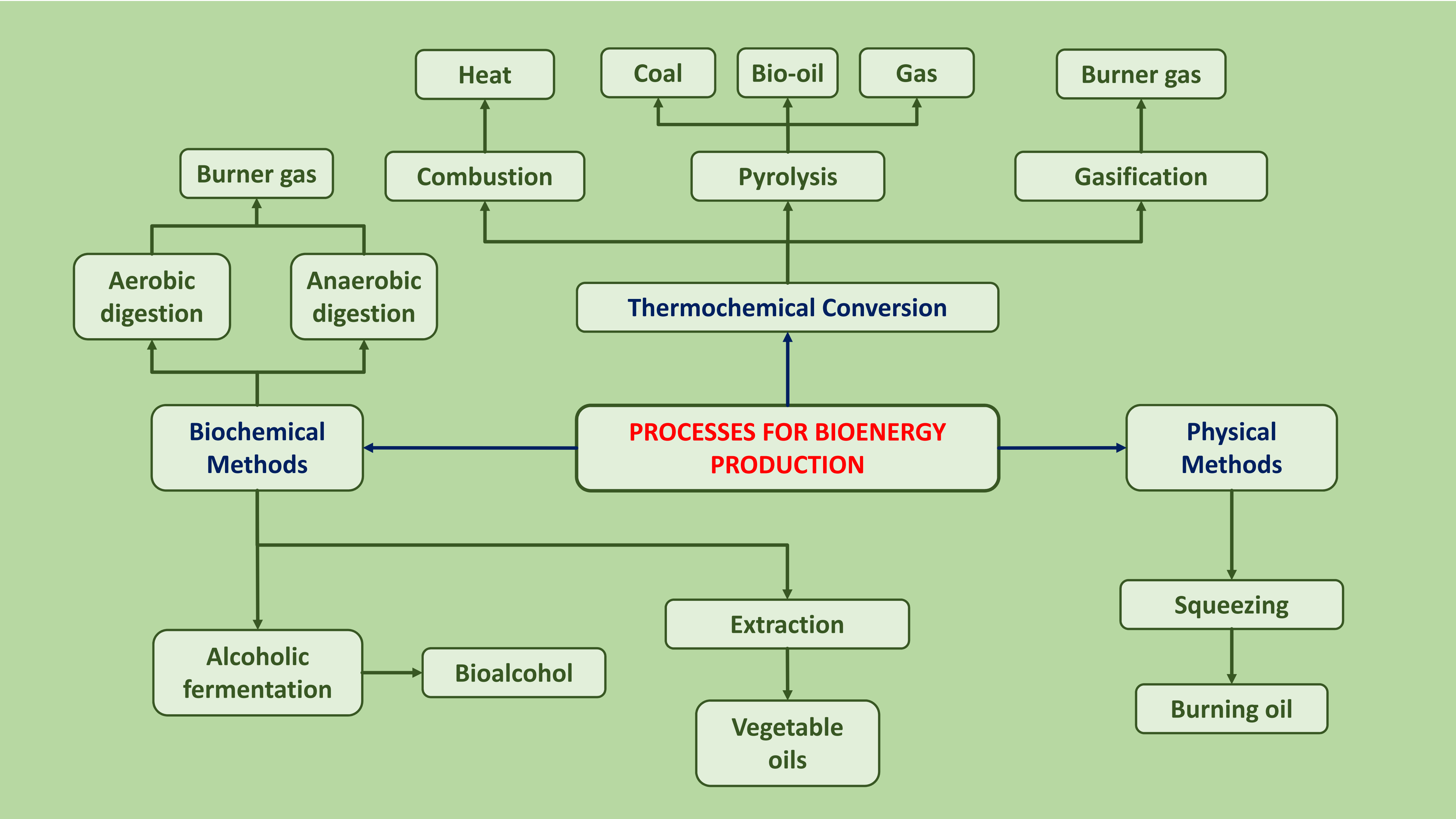
# Management of the generated biomass





Heat
Coal
Bio-oil
Gas
Burner gas
Burner gas
Combustion
Pyrolysis
Gasification
Aerobic digestion
Anaerobic digestion
Thermochemical Conversion
Biochemical Methods
PROCESSES FOR BIOENERGY PRODUCTION
Physical Methods
Squeezing
Extraction
Alcoholic fermentation
Bioalcohol
Vegetable oils
Burning oil

# Management of the generated biomass

**Biomass from phytoremediation**

- ✓ Potential use as energy crops
  - ✓ Degradability and biogas generation potential (ignocellulosic components/carbohydrate rich, high content of biodegradable organic matter)
  - ✓ Biomass thermic potential (low water and ashes content; high amount of raw lignin)
- ✓ TEs effects on biomass energetic potential

**Other advantages**

Impact on agricultural soil

- ✓ (Indirect) Land use change
- ✓ Bio-fuel life cycle emissions ↓

# Trace elements - Contamination - Phytoremediation

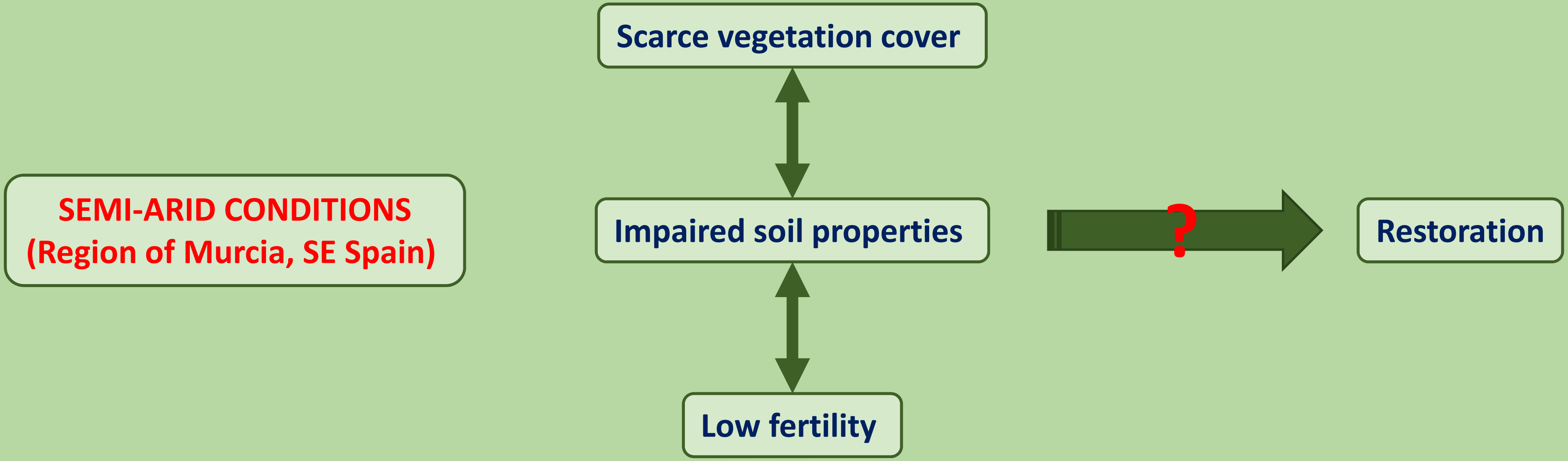
**MAJOR NEED:**
**IMPLEMENTATION/PUT INTO PRACTICE**

**Site particularities (topography, climate, etc.)**

**Final aim (stabilization/extraction)**

**Remediation options (e.g., GRO)** → **Added value options** → **REAL COST/TIME**

# Trace elements - Contamination - Phytoremediation



# La Unión-Cartagena Mining Area (Murcia, Spain)

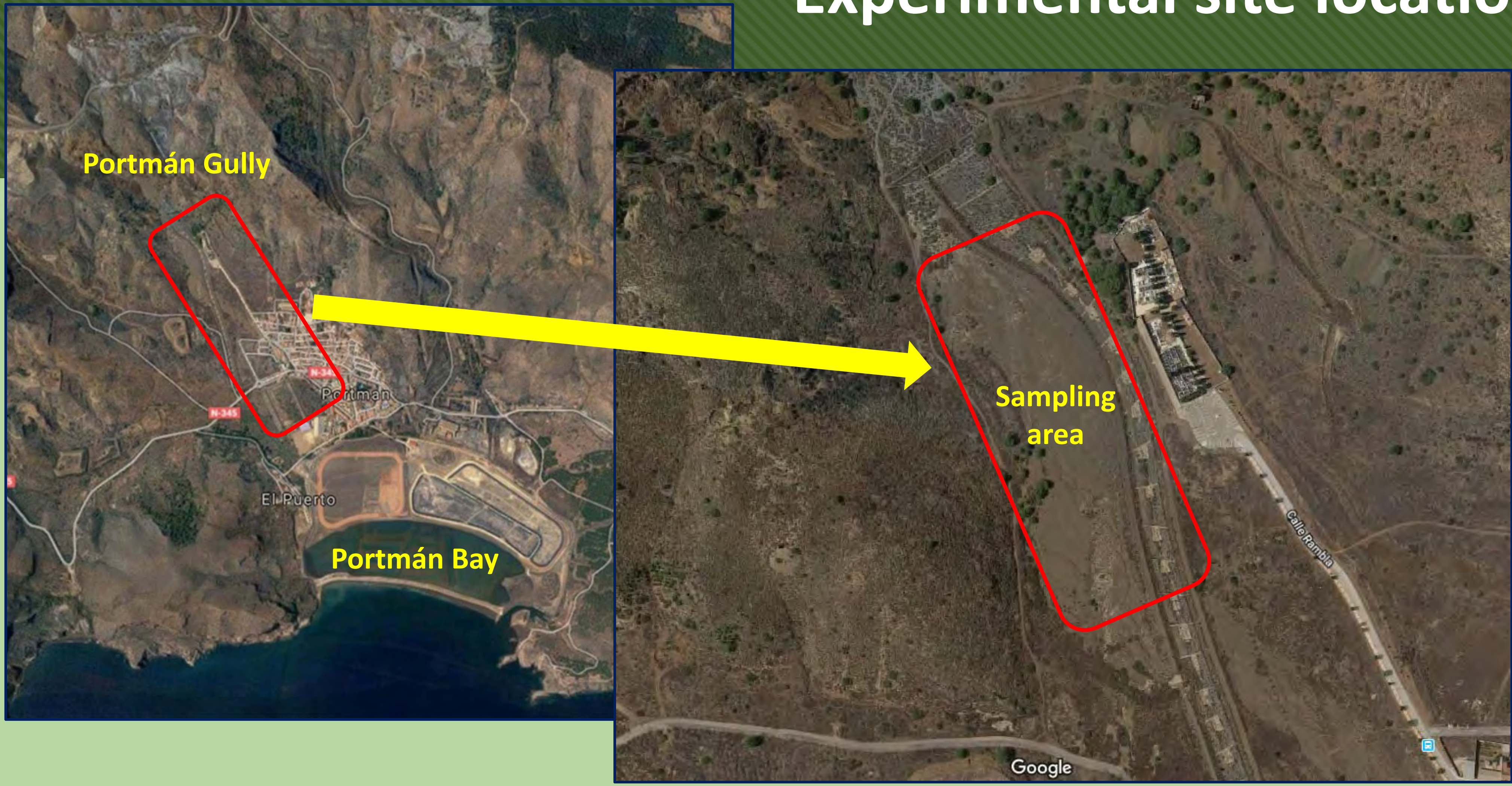
# La Unión-Cartagena Mining Area (Murcia, Spain)

# Case study 1 - Options for mine site restoration

1. Soil survey within the mining area of La Unión-Cartagena (Murcia, Spain)
2. Selection of amendments
3. Plant species: adapted, added value
4. Pot test: performance of plants and amendments
5. Upscale: biomass production, eco-toxicity

# Experimental site location

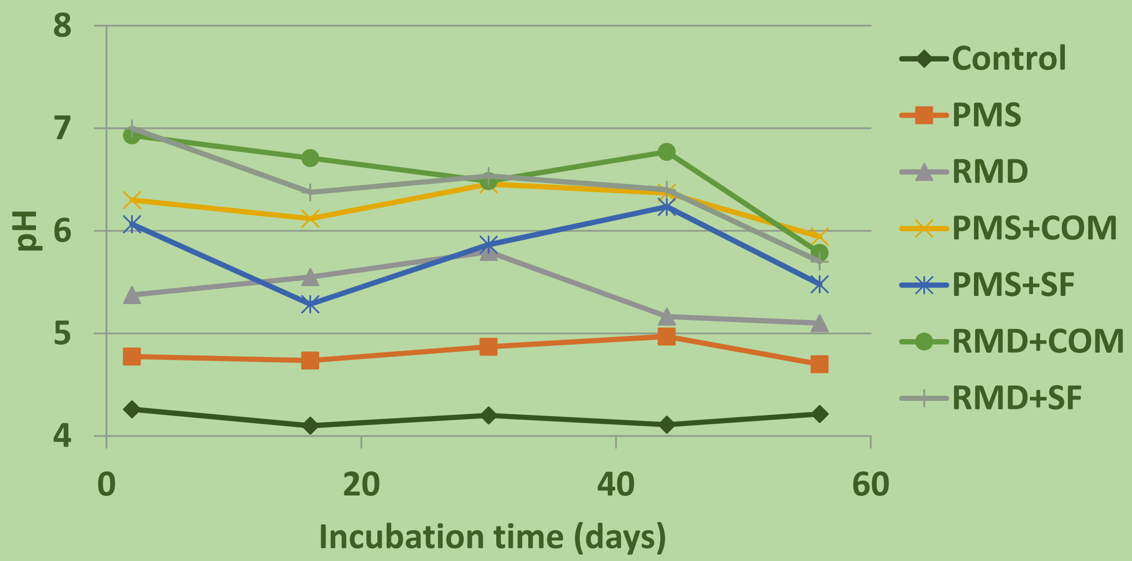
# Experimental site location



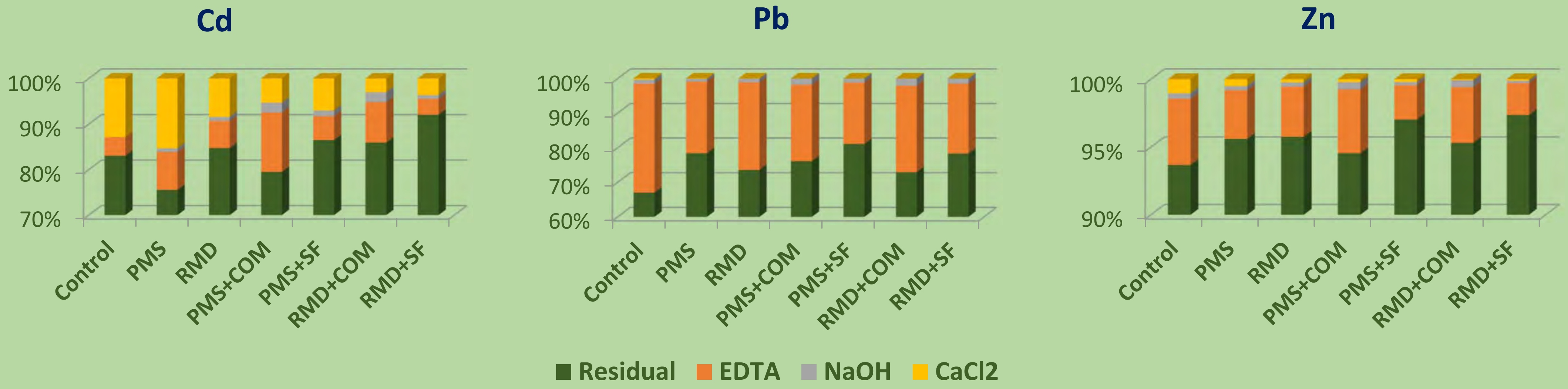

# Soil characterisation and conditioning

| | Portmán soil | $CaCl_2/NaHCO_3$ |
|---|---|---|
| pH | 4.16 | - |
| TOC ($g\ kg^{-1}$) | 2.7 | - |
| EC ($mS\ cm^{-1}$) | 2.22 | - |
| As ($mg\ kg^{-1}$) | 1976 | 0.67 |
| Cd ($mg\ kg^{-1}$) | 12 | 0.2 |
| Cu ($mg\ kg^{-1}$) | 230 | 1.6 |
| Fe ($mg\ kg^{-1}$) | 214747 | 0.5 |
| Mn ($mg\ kg^{-1}$) | 968 | 9.3 |
| Pb ($mg\ kg^{-1}$) | 19129 | 1667 |
| Zn ($mg\ kg^{-1}$) | 2257 | 28 |

Paper mill sludge (**PMS**) - Red mud derivative (**RMD**)
Pig slurry (solid fraction, **SF**) - Compost (olive mil waste, **COM**)



# Sequential extractions



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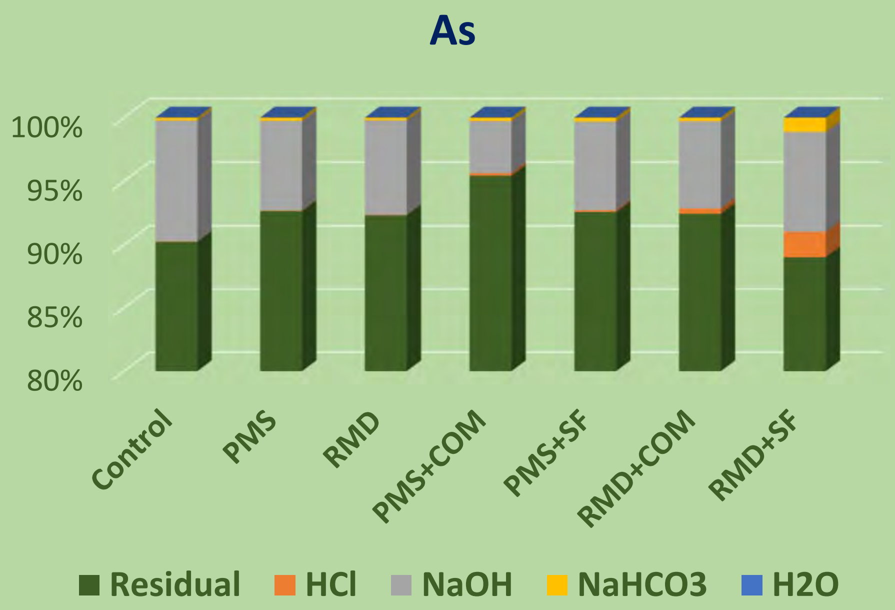
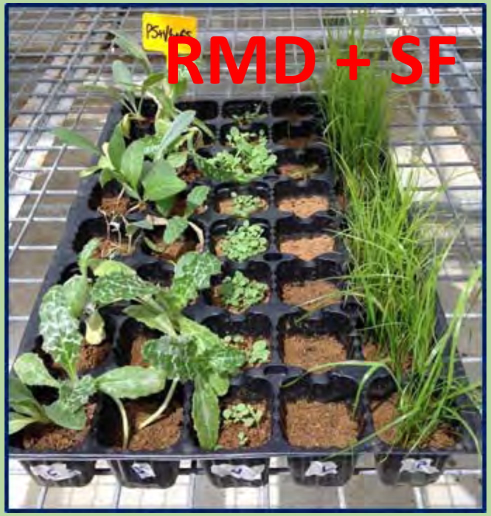


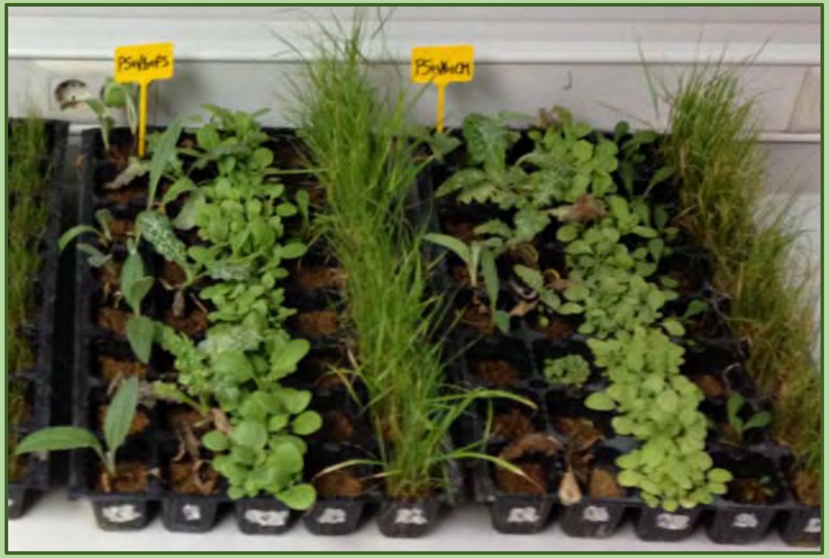
# Plants test






# Plants test




- ✓ *Cynara cardunculus* ↓
- ✓ *Silybum marianum* ↑
- ✓ *Nicotiana glauca* ↑
- ✓ *Limonium caesium* ↓
- ✓ *Piptatherum miliaceum* ↑

# Pot test

## Soil and amendments

| | Soil | SF | PMS | RMD |
|---|---|---|---|---|
| pH | 3.80 | 7.31 | 8.87 | 10.9 |
| EC (dS m$^{-1}$) | 0.19 | 6.85 | 4.40 | 0.14 |
| OM (%) | 0.28 | 68.6 | 32.2 | n.d. |
| TOC (g kg$^{-1}$) | 1.63 | 356 | 195 | 7.17 |
| TN (g kg$^{-1}$) | 0.31 | 32.8 | 20.0 | 0.15 |
| P (g kg$^{-1}$) | 0.29 | 7.7 | 0.26 | 0.37 |
| As (mgkg$^{-1}$) | 1976 | <0.1 | <0.1 | 4.68 |
| Cd (mg kg$^{-1}$) | 12.0 | 0.2 | 0.19 | 0.27 |
| Cu (mg kg$^{-1}$) | 230 | 226 | 184 | 55.7 |
| Fe (g kg$^{-1}$) | 215 | 1.36 | 9.10 | 90.2 |
| Mn (mg kg$^{-1}$) | 968 | 194 | 72.7 | 901 |
| Pb (mg kg$^{-1}$) | 19129 | 5.3 | 18.4 | 41.2 |
| Zn (mg kg$^{-1}$) | 2257 | 849 | 38.6 | 10.7 |

n.d.: not determined.

- ✓ Pig slurry (solid fraction, **SF**)
- ✓ Paper mill sludge (**PMS**)
- ✓ Red mud derivative (**RMD**)

# Pot test

***S. marianum***
***P. miliaceum***





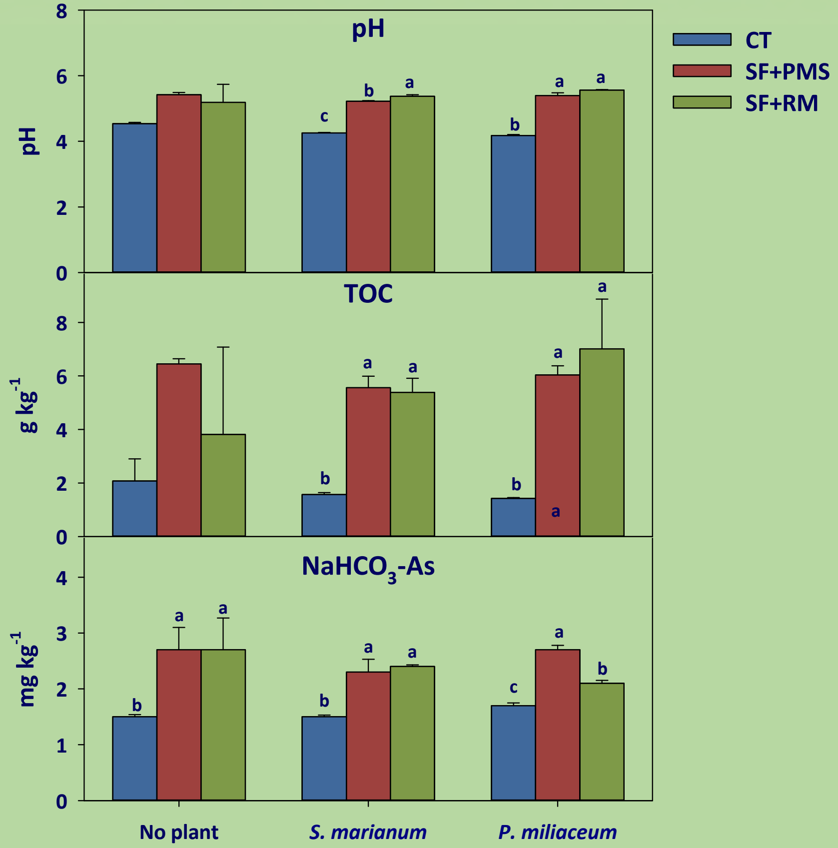
# Pot test

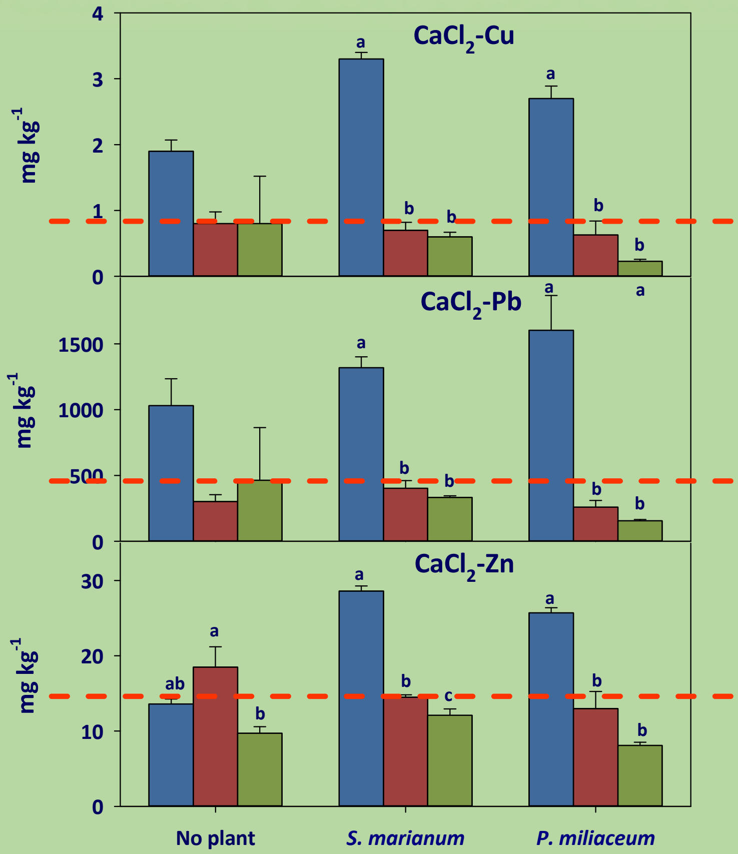
*N. glauca*
*H. annuus*

# Pot test Effects on soils

pH, TOC,

Metals & As extractability



# Pot test

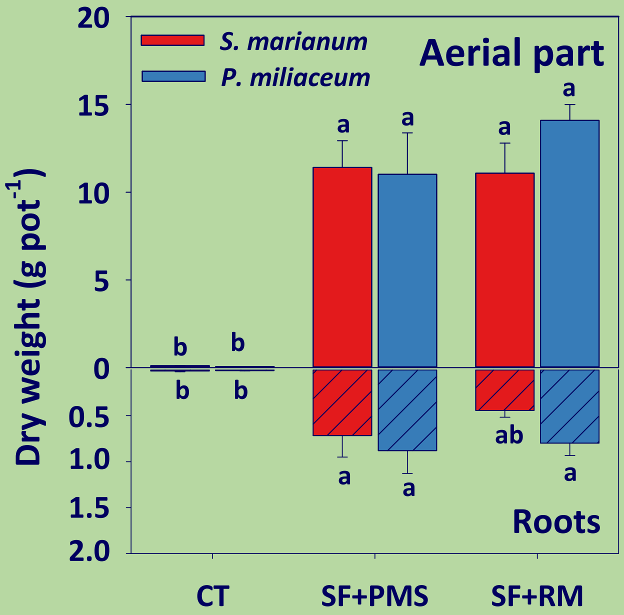
## Plants – TEs accumulation

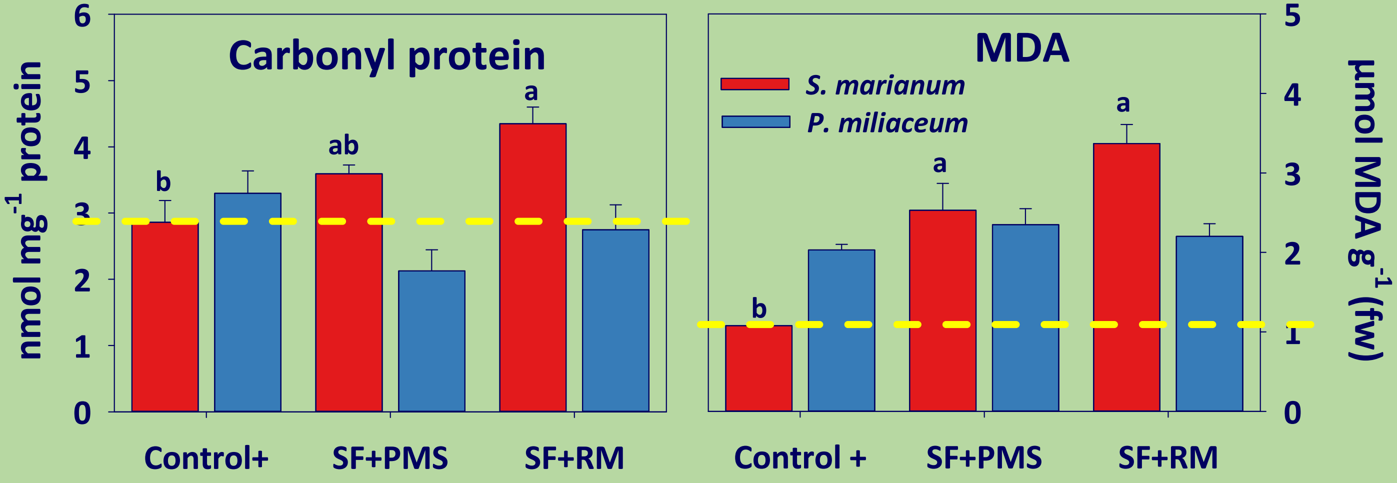
**TE CONCENTRATIONS (mg kg$^{-1}$ dw) IN THE PLANTS (mean ± se)**

| | As | Cd | Cr | Cu | Pb | Zn | Mn |
|---|---|---|---|---|---|---|---|
| *Piptatherum miliaceum* | | | | | | | |
| RM | 7.3 ± 1.20 | 0.05 ± 0.10 | 63.6 ± 9.5ab | 20.0 ± 1.0b | 91 ± 3.0 | 124 ± 2.5cd | 211 ± 8.0d |
| PMS | 8.4 ± 2.45 | 0.03 ± 0.02 | 25.1 ± 4.4b | 19.0 ± 1.2b | 114 ± 24.5 | 99 ± 0.1d | 168 ± 10.0cd |
| *Silybum marianum* | | | | | | | |
| RM | 2.5 ± 0.60 | 1.95 ± 0.15 | 73.5 ± 8.5ab | 21.3 ± 0.8b | 118 ± 18.5 | 293 ± 17.0b | 639 ± 4.0a |
| PMS | 3.2 ± 0.90 | 2.50 ± 0.50 | 123.0 ± 40a | 27.8 ± 0.6a | 183 ± 10.5 | 407 ± 12.5a | 577 ± 6.5b |
| *Helianthus annuus* | | | | | | | |
| RM | 0.6 ± 0.52 | 0.45 ± 0.05 | 12.4 ± 0.91b | 6.3 ± 0.4d | 87 ± 10.0 | 100 ± 7.0d | 229 ± 22.5c |
| PMS | 1.2 ± 0.15 | 0.59 ± 0.05 | 24.7 ± 5.20b | 7.9 ± 1.5d | 161 ± 5.5 | 145 ± 6.9c | 239 ± 8.0c |
| *Nicotiana glauca* | | | | | | | |
| RM | 2.6 ± 1.76 | 1.50 ± 0.06 | 21.8 ± 2.48b | 10.0 ± 1.1c | 225 ± 6.5 | 137 ± 9.5c | 72.5 ± 12.0e |
| PMS | 1.6 ± 0.37 | 1.59 ± 0.36 | 18.1 ± 1.87b | 10.1 ± 0.9c | 231 ± 26 | 137 ± 3.0c | 78.0 ± 5.0e |
| ANOVA | | | | | | | |
| TxP | n.s. | n.s. | * | ** | n.s. | ** | ** |

*, **: $P < 0.05$, and 0.01, respectively; n.s.: not significant. Post-hoc: Tukey's test at $P < 0.05$.

# Pot test **Plants - Oxidative stress**

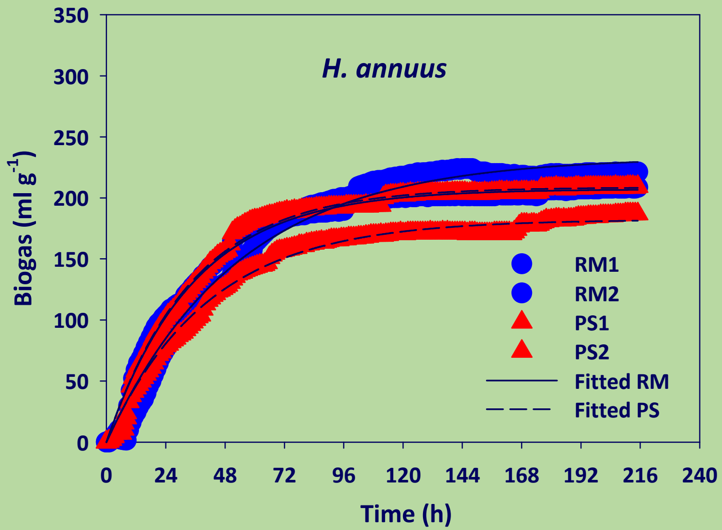


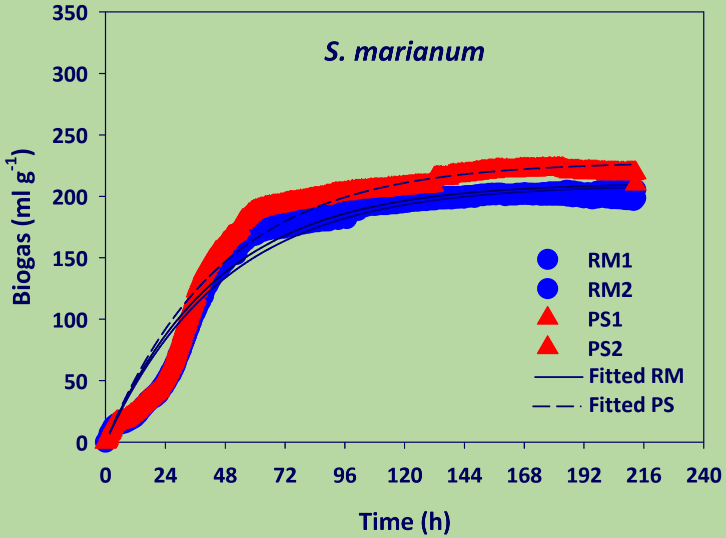



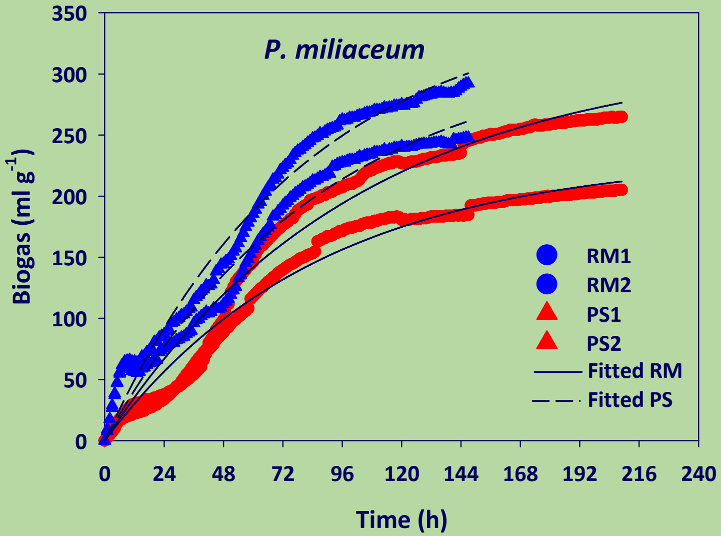

Clemente et al., 2019. *Chemosphere* 223, 223-231.

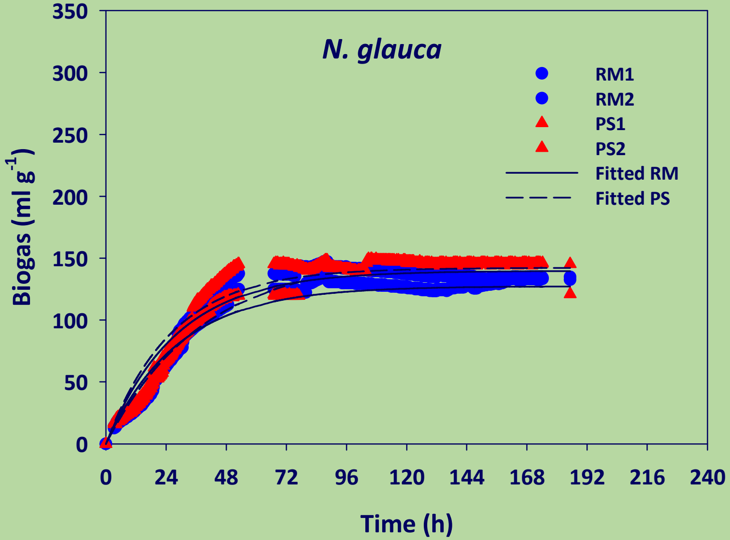
# Pot test Biomass valorisation

ANAEROBIC INCUBATION (ANKOM RF) - BIOGAS



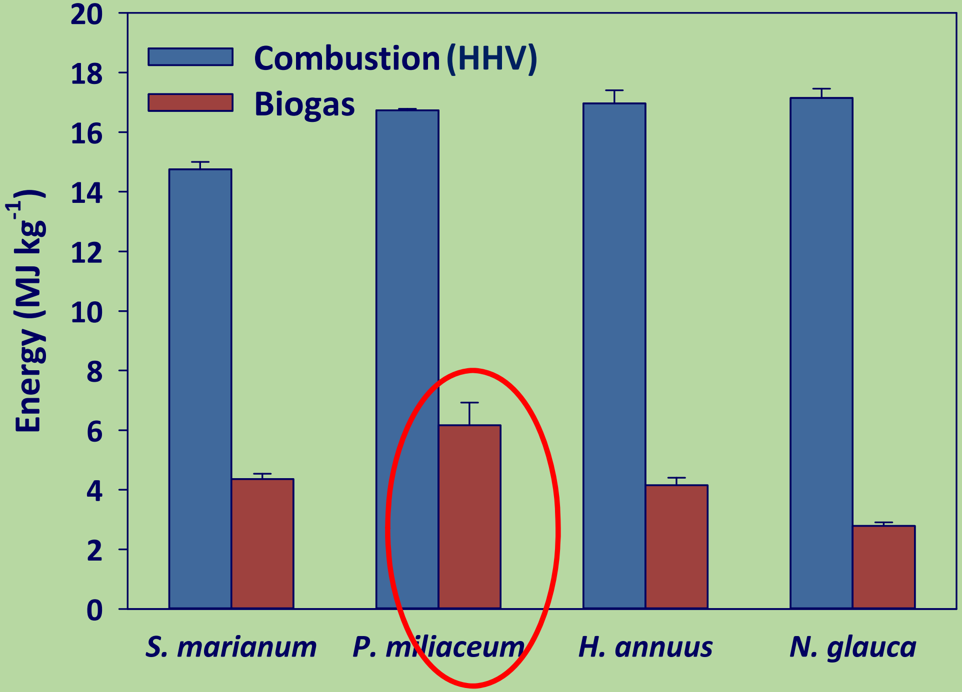




Bernal et al., 2019. *Biomass and Bioenergy* 126, 220-230.

# Pot test **Biomass valorisation**

HHV: Higher heating value (calculated from elemental composition)




Bernal et al., 2019. *Biomass and Bioenergy* 126, 220-230.

# Planter test

*Silybum marianum*

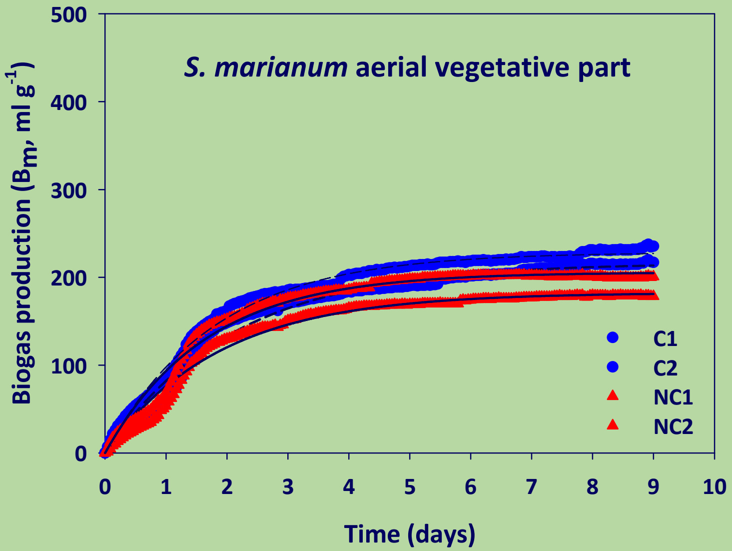
*Helianthus annuus*

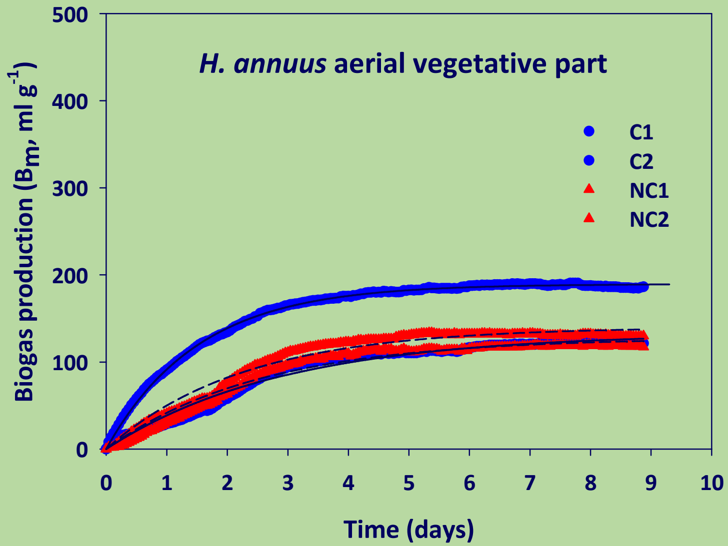
NON CONTAMINATED SOIL

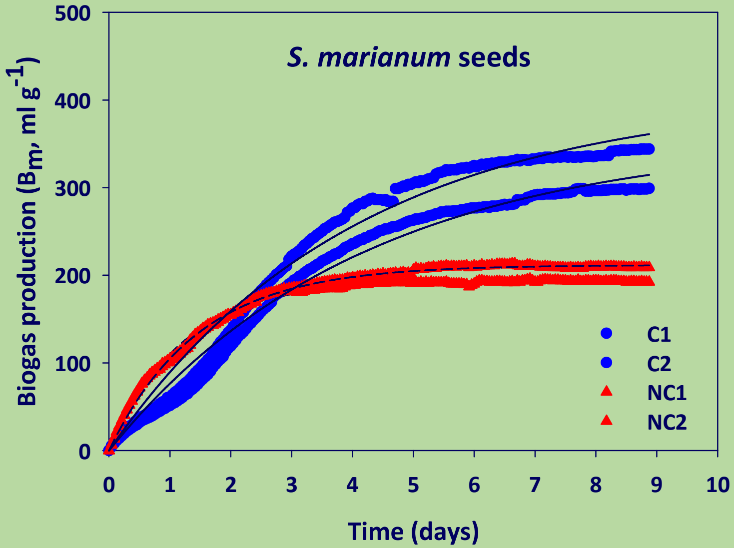
CONTAMINATED SOIL
SF + PMS

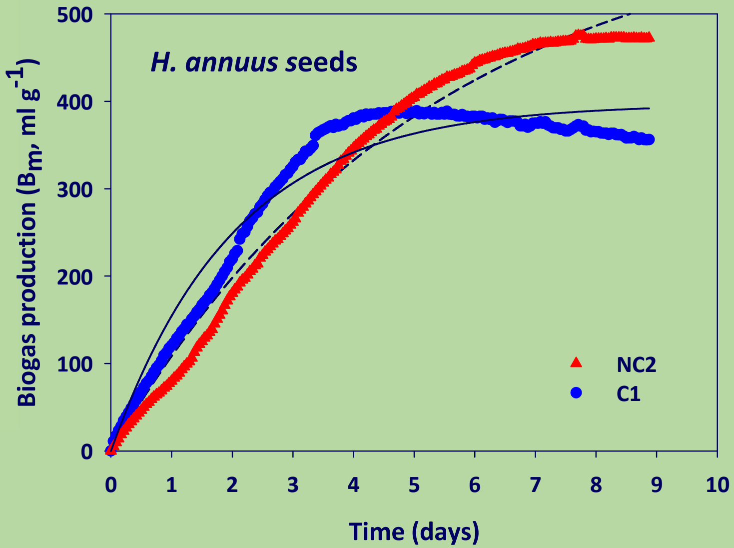
# Planter test Biomass valorisation

ANAEROBIC INCUBATION - BIOGAS



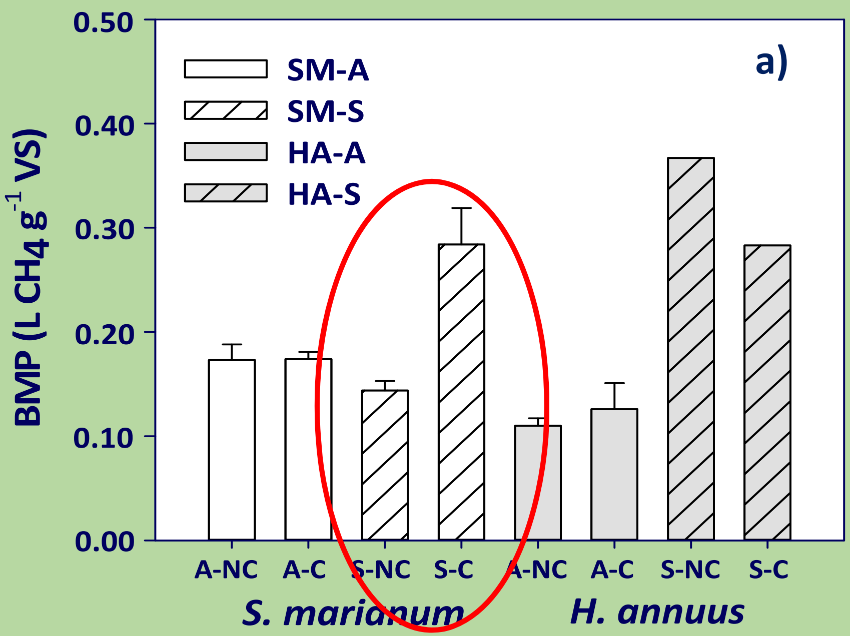



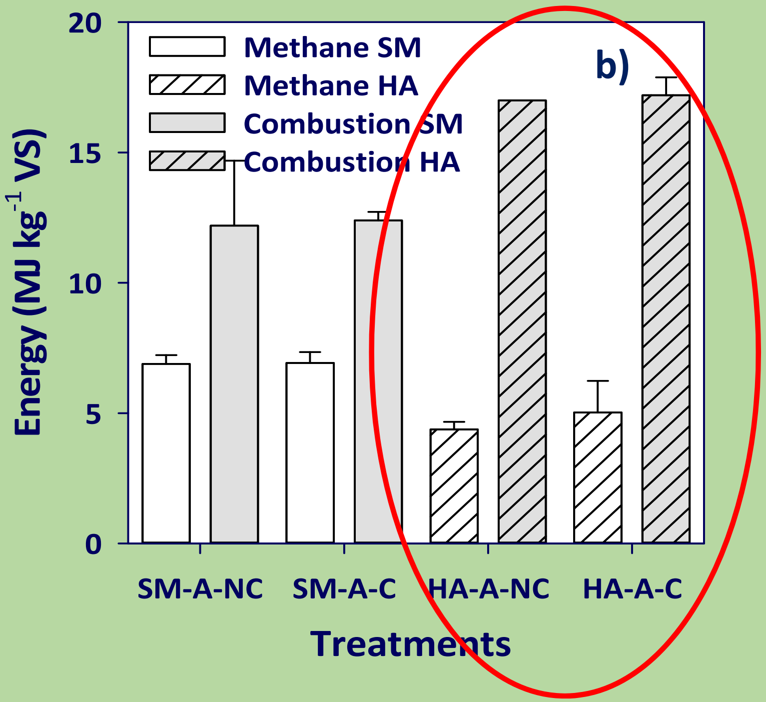

Hunce et al., 2019. *Industrial Crops & Products* 135, 206-216.

# Planter test    Biomass valorisation

a) Biomethane production potentials (BMP)

b) Comparison of energy production methods: anaerobic digestion (methane) and combustion (HHV)

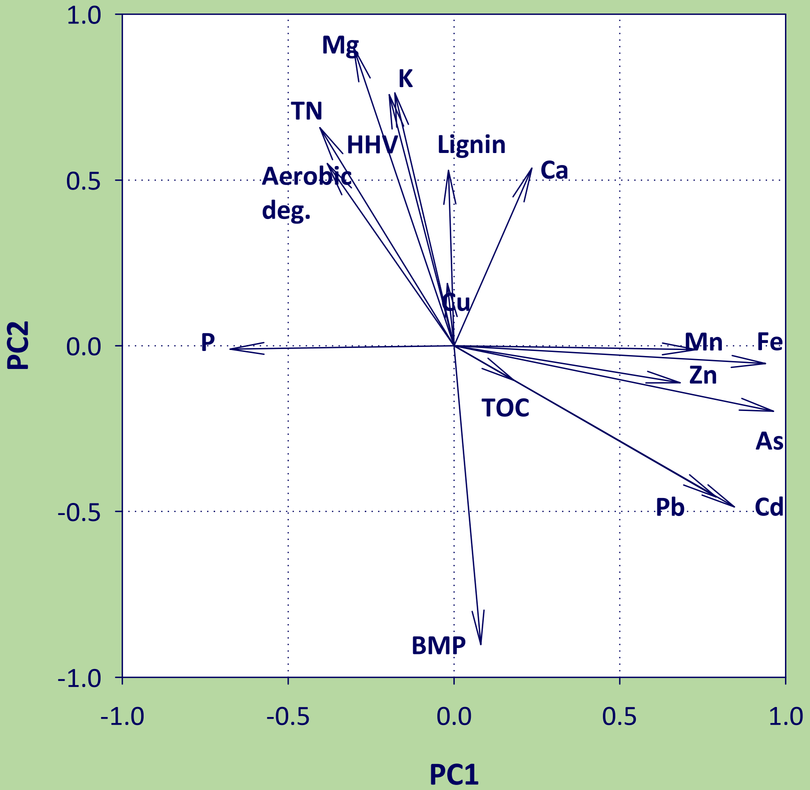


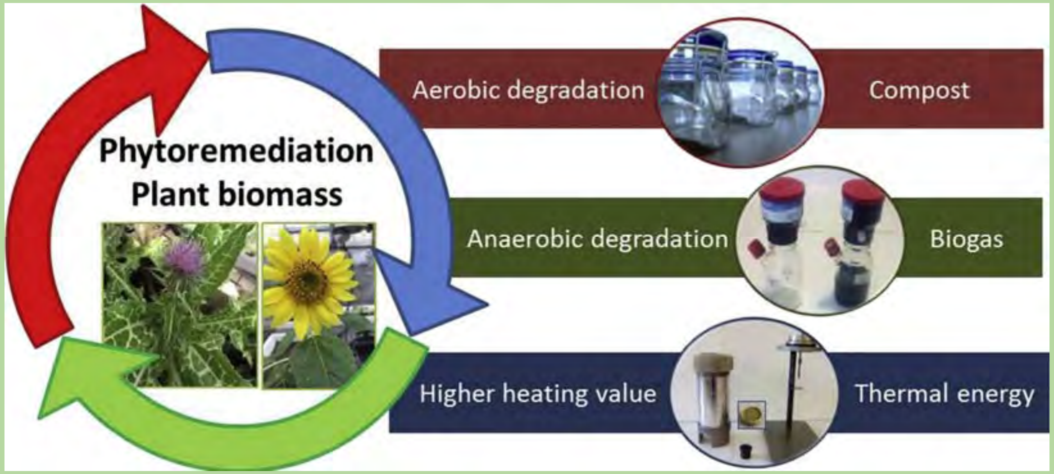

Hunce et al., 2019. *Industrial Crops & Products* 135, 206-216.

SM: *S. marianum*; HA: *H. annuus*; A: aerial part; S: seeds; NC: non-contaminated C: contaminated

# Planter test Principal Component Analysis




- ✓ BMP (inversely), HHV and aerobic degradation related to lignin and nutrient content in the plants
- ✓ Metals and As concentration do not affect degradability and energy production potential




Hunce et al., 2019. *Industrial Crops & Products* 135, 206-216.

# Planter test Eco-toxicological evaluation

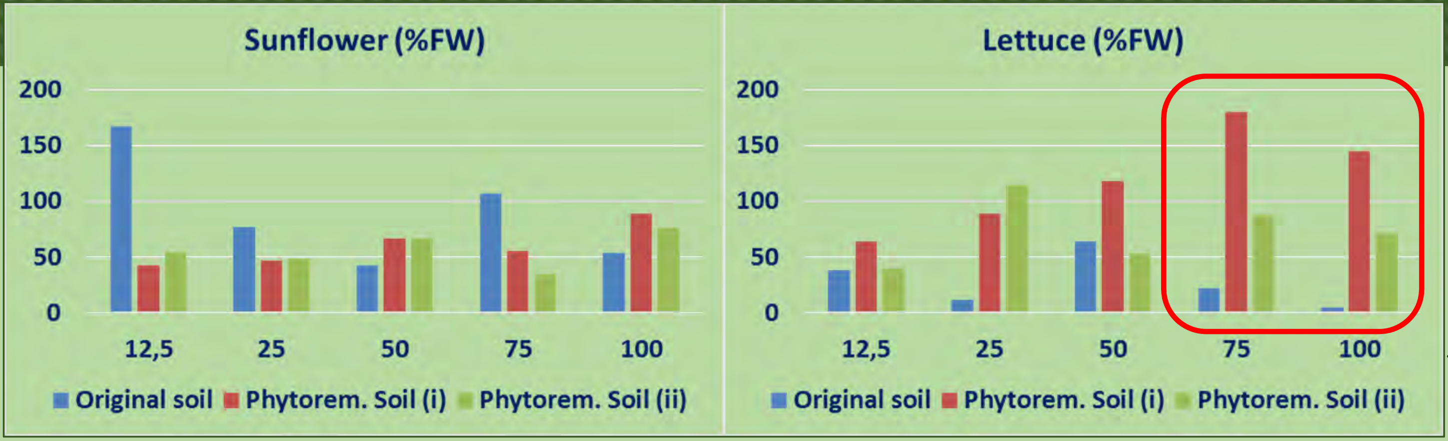
**Plant growth test (direct) - *Helianthus annuus* & *Lactuca sativa***

**Artificial soil (OCDE)**
**0.6 kg peat**
**1.6 kg clay**
**5.6 kg sand**
**0.08 kg $CaCO_3$**

**Soil dilutions**

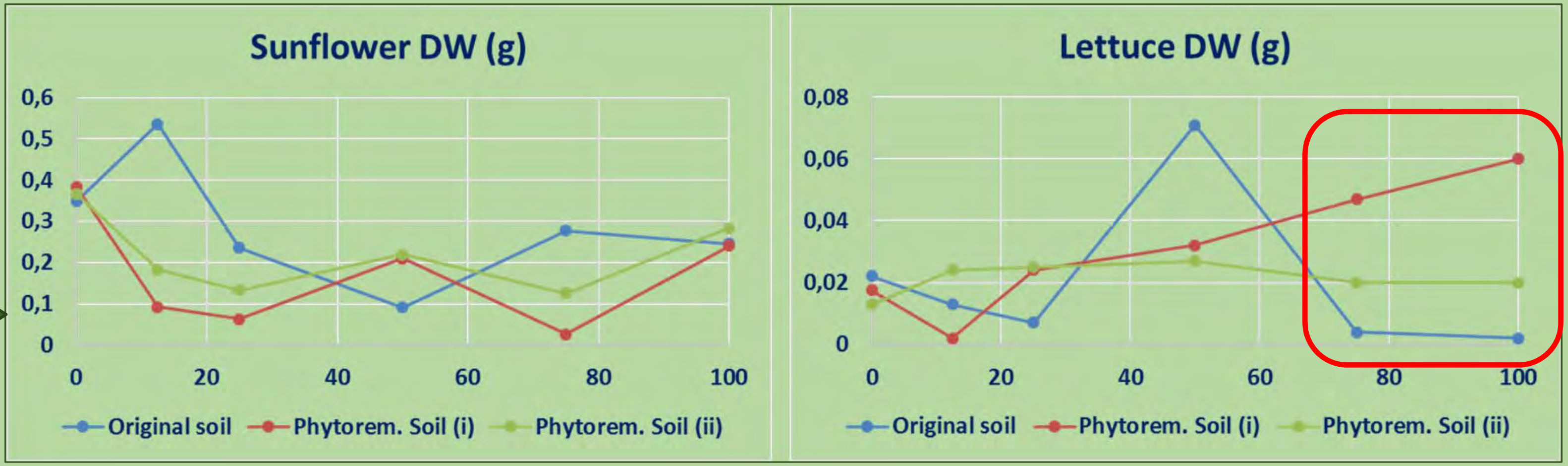
***Helianthus annuus/Lactuca sativa* cultivated in growth chamber**

# Planter test Eco-toxicological evaluation

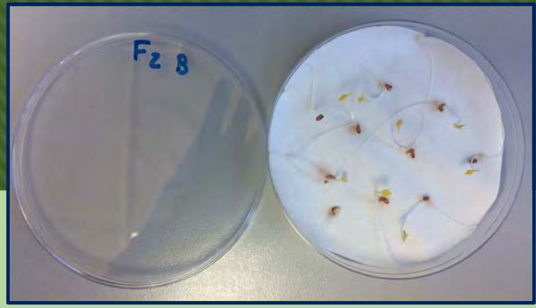



%Fresh weight compared to artificial (clean ) soil

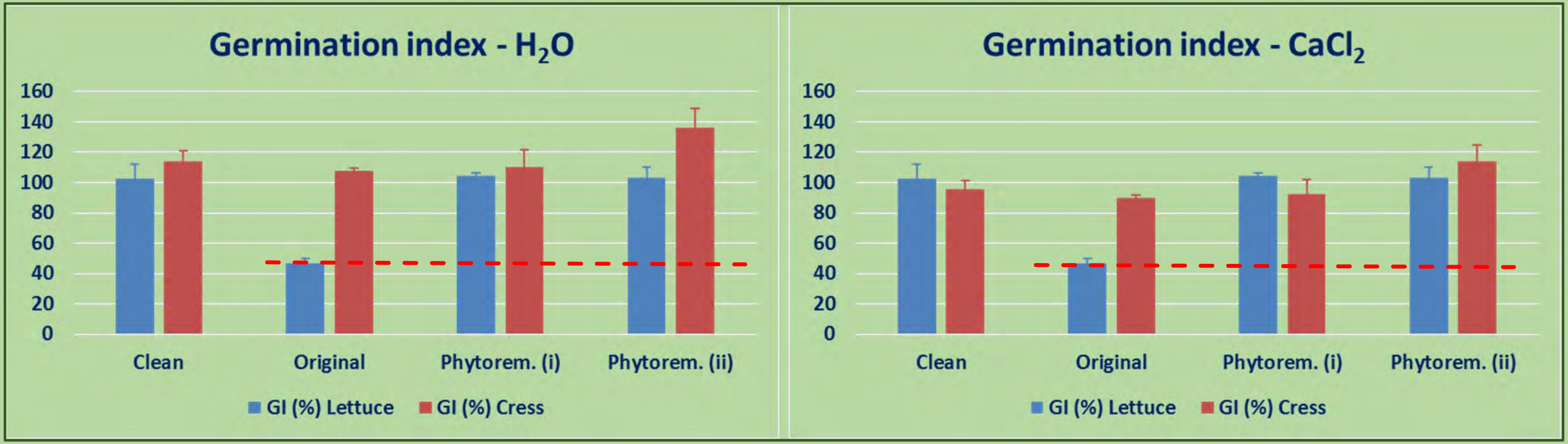
Total dry weight per soil dilution



# Planter test Eco-toxicological evaluation

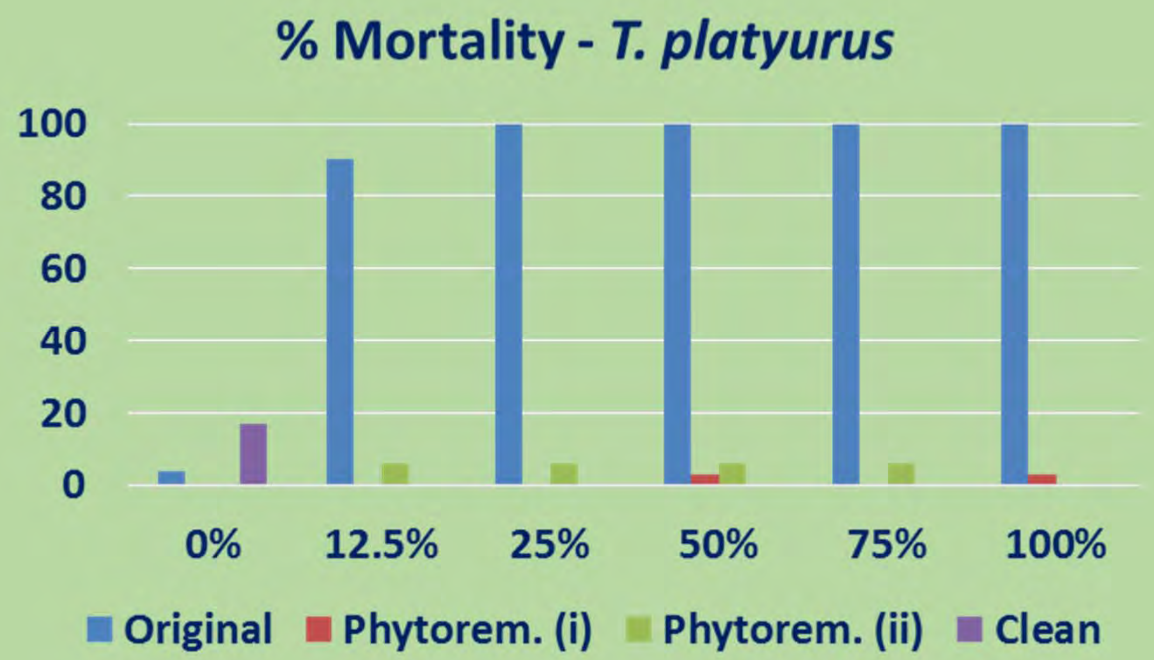



**Germination index (indirect) - *Lepidium sativum* & *Lactuca sativa***



# Planter test **Eco-toxicological evaluation**

**Mortality test (indirect) – *Thamnocephalus platyurus***



# Case study 1 - CONCLUSIONS

- ✓ SF + inorganic amendments stabilized TEs in a mine soil
- ✓ Plants TE concentrations within common ranges for mine soils
- ✓ Carbonyl proteins and MDA levels confirmed oxidative stress in plants
- ✓ Amendments-native species combination suitable for mine soils phytostabilization
- ✓ No effects of TEs in the plants on bioenergy production were observed
- ✓ Combustion was the best option for bioenergy production from these plants
- ✓ Phytostabilized soils showed no toxicity: successful remediation

# Case study 2 - Phytostabilization of a mine affected soil


# Case study 2 - Phytostabilization of a mine affected soil

# Case study 2 - Phytostabilization of a mine affected soil

| | Soil LL |
|---|---|
| pH | 6.18 ± 0.05 |
| OM (%) | 0.23 ± 0.02 |
| TOC (g $kg^{-1}$) | 1.35 ± 0.10 |
| $N_T$ (g $kg^{-1}$) | 0.45 ± 0.07 |
| Fe (g $kg^{-1}$) | 108 ± 1 |
| Zn (mg $kg^{-1}$) | 9686 ± 252 |
| Pb (mg $kg^{-1}$) | 10,188 ± 97 |
| Cu (mg $kg^{-1}$) | 193 ± 8 |
| Mn (mg $kg^{-1}$) | 4073 ± 368 |
| Cd (mg $kg^{-1}$) | 19 ± 1 |
| As (mg $kg^{-1}$) | 664 ± 28 |

# Case study 2 - Phytostabilization of a mine affected soil

PIG SLURRY
(60 $m^3$ $ha^{-1}$)

COMPOST
(60 t $ha^{-1}$)

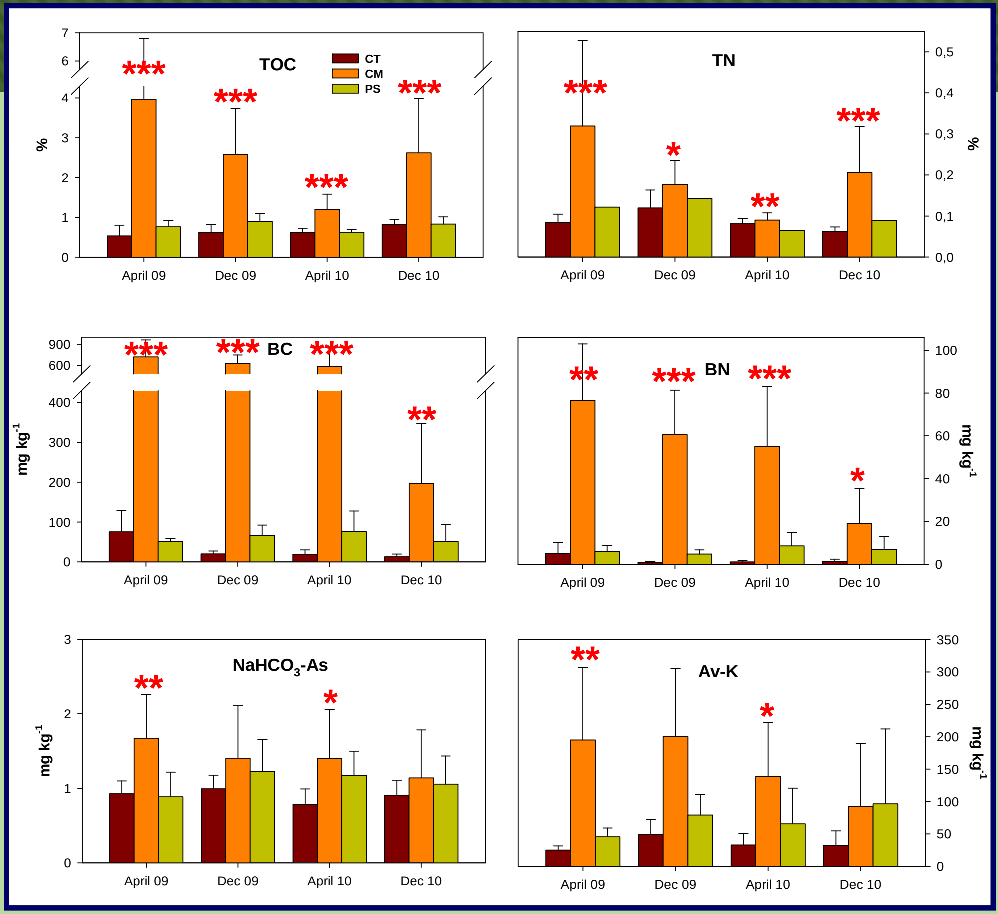
HYDRATED LIME
(>93% CaO)
(2.3 t $ha^{-1}$)

# Case study 2 - Phytostabilization of a mine affected soil

***Atriplex halimus* L.**

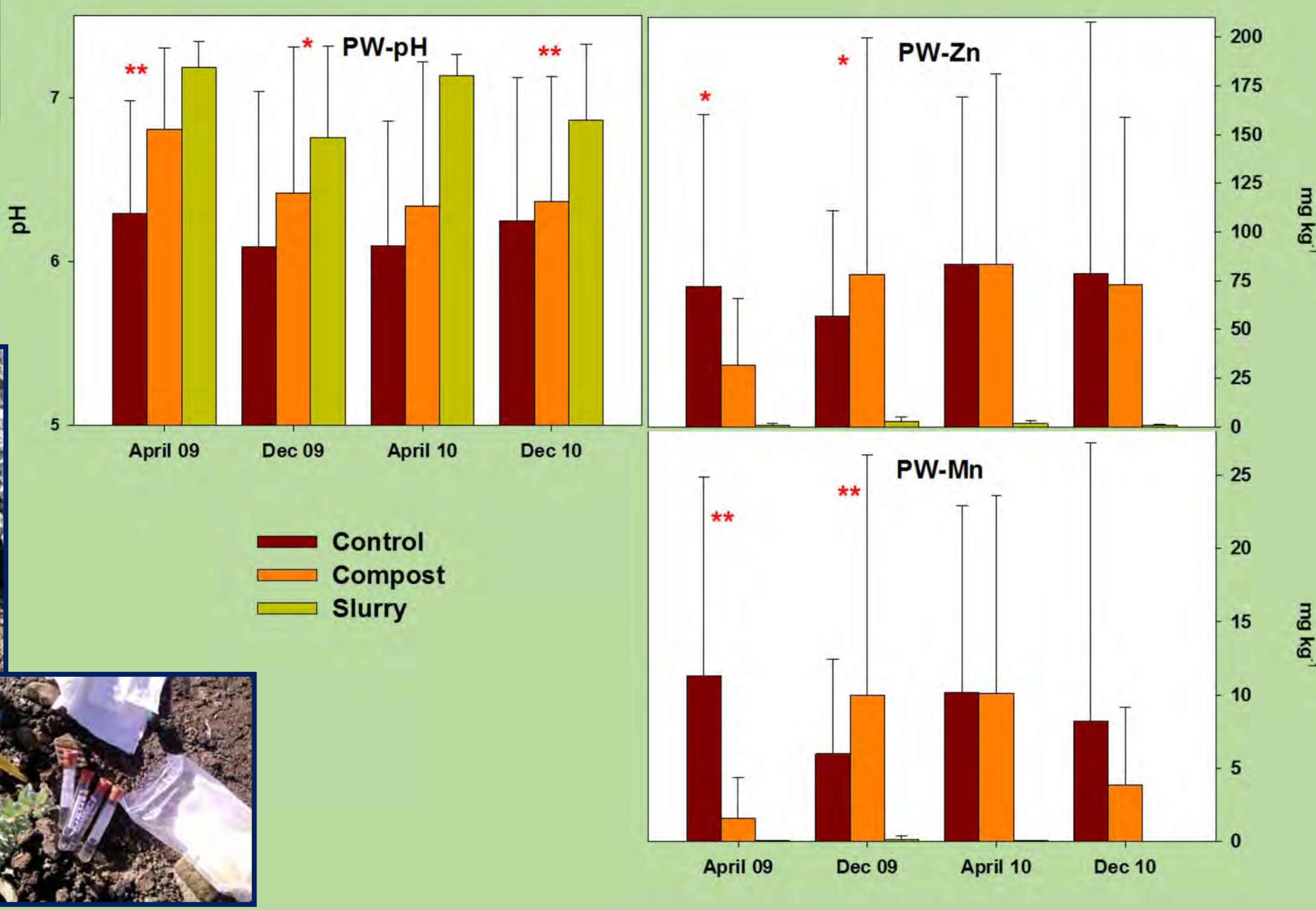
***Bituminaria bituminosa* L.**

# Case study 2 - SOILS




Clemente et al., 2012. *J. Hazard. Mat.* 233-234, 63-71.

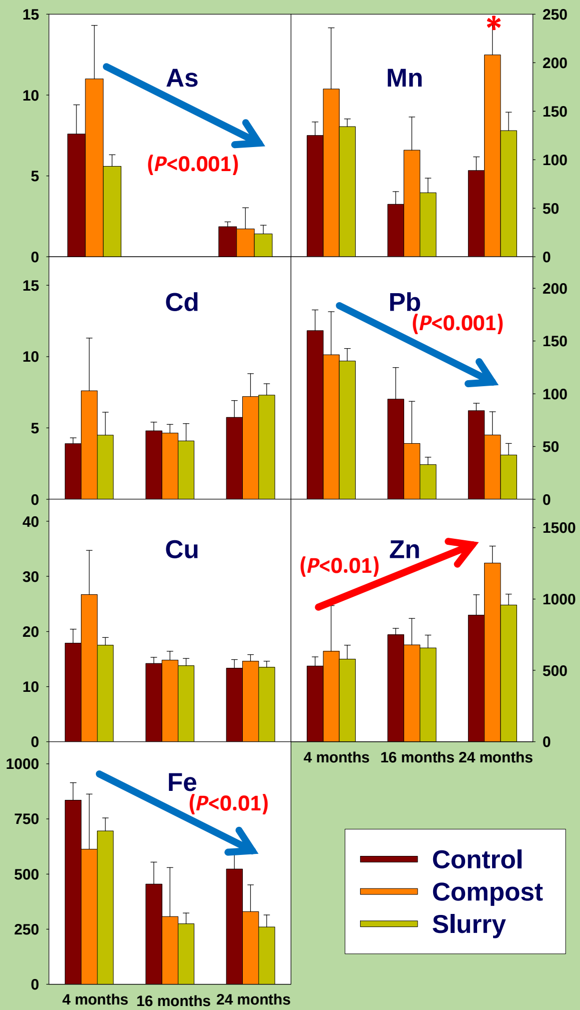
# Case study 2 – PORE WATER




Clemente et al., 2012. *J. Hazard. Mat.* 233-234, 63-71.

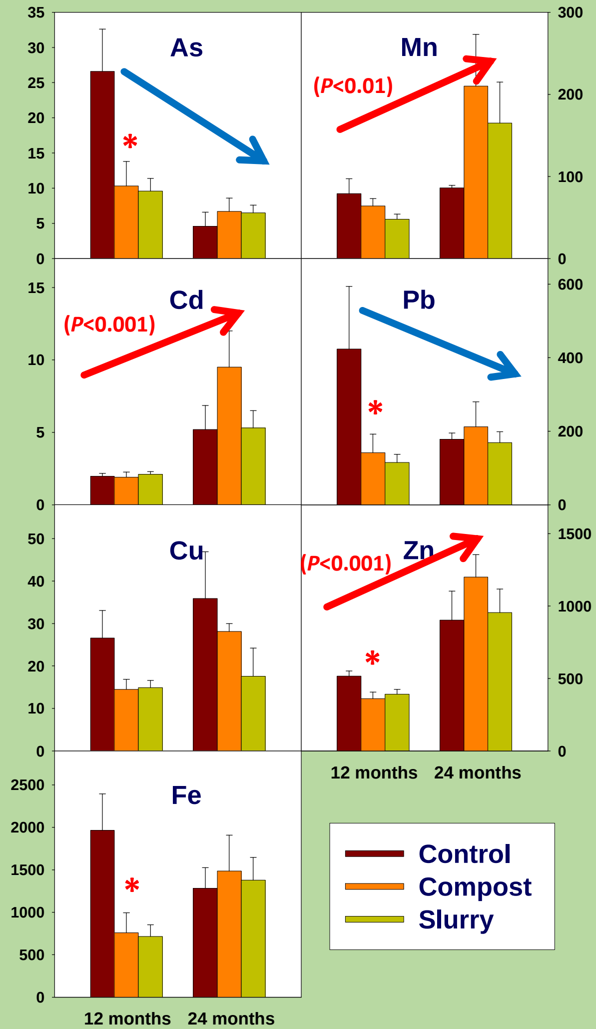
# Case study 2

## PLANTS




LEAF (mg kg-1)

FRUIT (mg kg-1)




Clemente et al., 2012. *J. Hazard. Mat.* 233-234, 63-71.

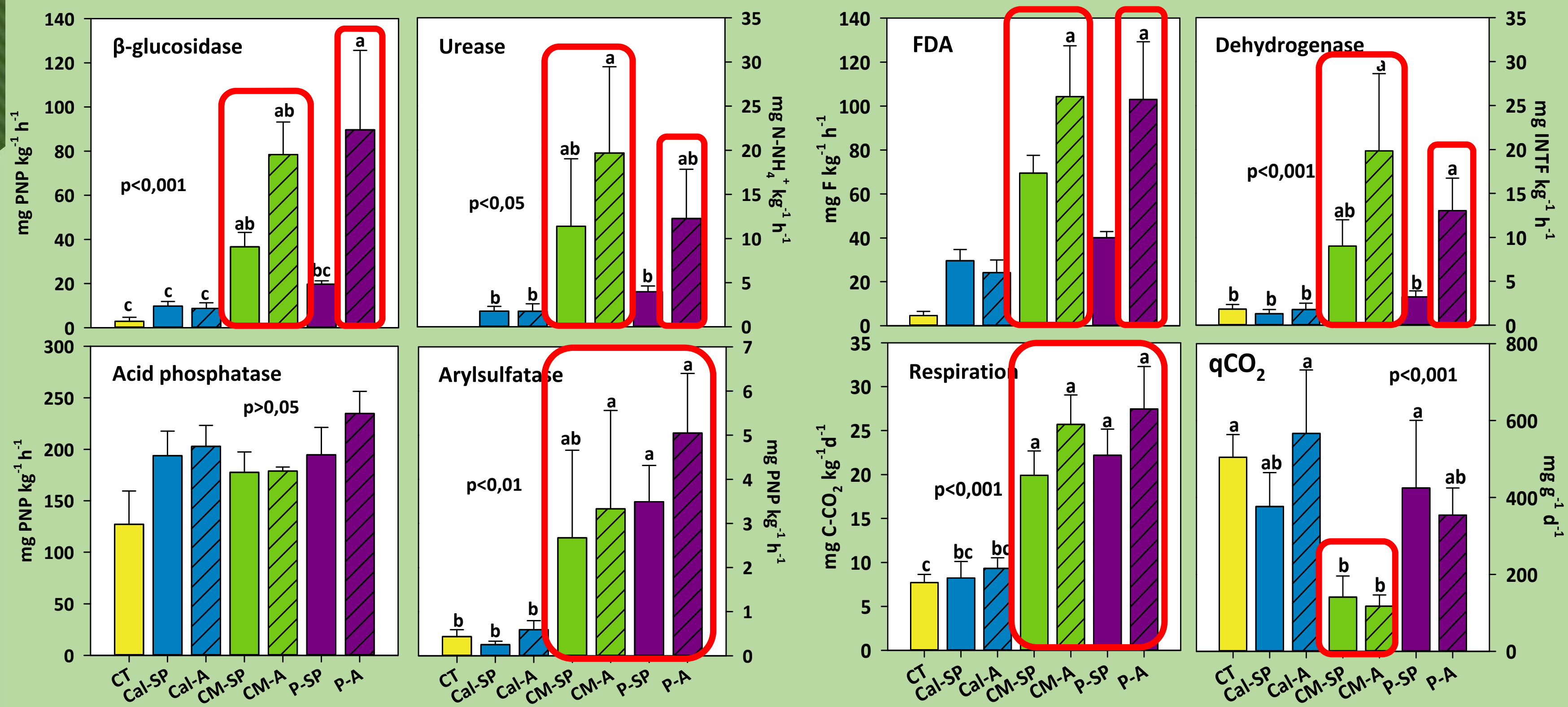
# Case study 2 - PLANTS

**2 years after amendments addition**

# Case study 2 – Microbial indicators

| Treatment | $B_C$ mg kg$^{-1}$ | $B_N$ mg kg$^{-1}$ |
|---|---|---|
| Cal-SP | 24 c | 0.3 c |
| Cal-A | 20 c | 0.2 c |
| CM-SP | 167 a | 10 a |
| CM-A | 250 a | 20 a |
| P-SP | 29 bc | 0.4 bc |
| P-A | 91 ab | 4.0 ab |
| CT | 16 c | 0.7 bc |
| T | *** | ** |
| Pl | ns | ns |
| TxPl | *** | *** |

**Biomass**




**Functional activity**: hydrolases (C, N & S cycle; catalytic potential (FDA); microbial community (dehydrogenase, respiration, $qCO_2$)

Pardo et al., 2014. *J. Hazard. Mat.* 268, 68-76.

# Case study 2 – Microbial indicators

**CLPPs (community level physiological profiles): BIOLOG ECOPLATES**

**Average well color development (AWCD): overall functional activity of soil**

| Treatment | S | H’ | AWCD |
|---|---|---|---|
| **Cal-SP** | 6.0 ab | 2.7 a | 0.10 ab |
| **Cal-A** | 7.0 ab | 2.4 a | 0.11 ab |
| **CM-SP** | 14.8 a | 3.6 a | 0.38 a |
| **CM-A** | 17.0 a | 3.7 a | 0.43 a |
| **P-SP** | 8.0 ab | 2.3 a | 0.23 ab |
| **P-A** | 12.3 a | 3.2 a | 0.23 ab |
| **CT** | 1.2 b | 0.4 b | 0.01 b |
| T | *** | *** | |
| Pl | ns | ns | |
| TxPl | ** | ** | |

**Functional diversity: S: species richness (number of substrates used); H’: Shannon similarity index (uniformity in the distribution of the microbial community)**

**Pardo et al., 2014. *J. Hazard. Mat.* 268, 68-76.**

# Case study 2 – Eco-toxicological tests

## Plant growth test (direct) - *Zea mays* & *Lactuca sativa*



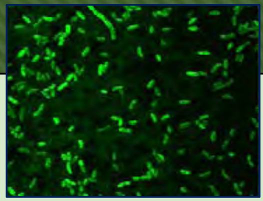
| Treatment | *Z. mays* | | *L. sativa* | |
|---|---|---|---|---|
| | $LC_{50}$ | $EC_{50}$ | $LC_{50}$ | $EC_{50}$ |
| Cal-SP | NT | 85.75 | 58.19 | 20.02 |
| Cal-A | NT | 80.50 | 46.68 | 19.73 |
| CM-SP | NT | NT | NT | 18.31 |
| CM-A | NT | NT | NT | NT |
| P-SP | NT | 93.31 | 59.86 | 13.39 |
| PCT-A | NT | 91.70 | NT | NT |
| CT | NT | 70.85 | 36.68 | 4.95 |

**$LC_{50}$ & $EC_{50}$**: dose of contaminated soil (v/v) that provokes 50% emergence/growth inhibition, respectively. NT: non toxic

**Pardo et al., 2014. *J. Hazard. Mat.* 268, 68-76.**

# Case study 2 – Eco-toxicological tests

## Indirect assays:




- *Vibrio fischeri* (luminescence inhibition test)
- *Thamnocephalus platyurus* (mortality test)
- *Lepidium sativum* & *Lactuca sativa* (germination test)

$EC_{50}$ (v/v)

| Treatment | *V. fischeri* | | *T. platyurus* |
|---|---|---|---|
| | t = 15 min | t = 30 min | |
| Cal-SP | 62,52 | 57,97 | 78,83 |
| Cal-A | 60,76 | 59,77 | 73,53 |
| CM-SP | 62,55 | 61,15 | 93,82 |
| CM-A | 47,98 | 45,79 | 84,76 |
| P-SP | 54,01 | 49,51 | 82,28 |
| P-A | 62,29 | 60,86 | 78,78 |
| CT | 61,69 | 61,46 | 10,15 |

| *L. sativum* | | | |
|---|---|---|---|
| Treatment | G (%) | R(%) | GI(%) |
| Cal-SP | 87,8 | 51,8 d | 45,4 c |
| Cal-A | 84,7 | 51,9 d | 43,9 c |
| CM-SP | 91,8 | 64,0 c | 58,7 b |
| CM-A | 96,9 | 71,8 ab | 69,6 a |
| P-SP | 91,8 | 67,9 bc | 62,3 ab |
| P-A | 88,8 | 72,6 a | 64,4 ab |
| CT | 87,8 | 47,0 d | 41,3 c |
| ANOVA | ns | *** | *** |

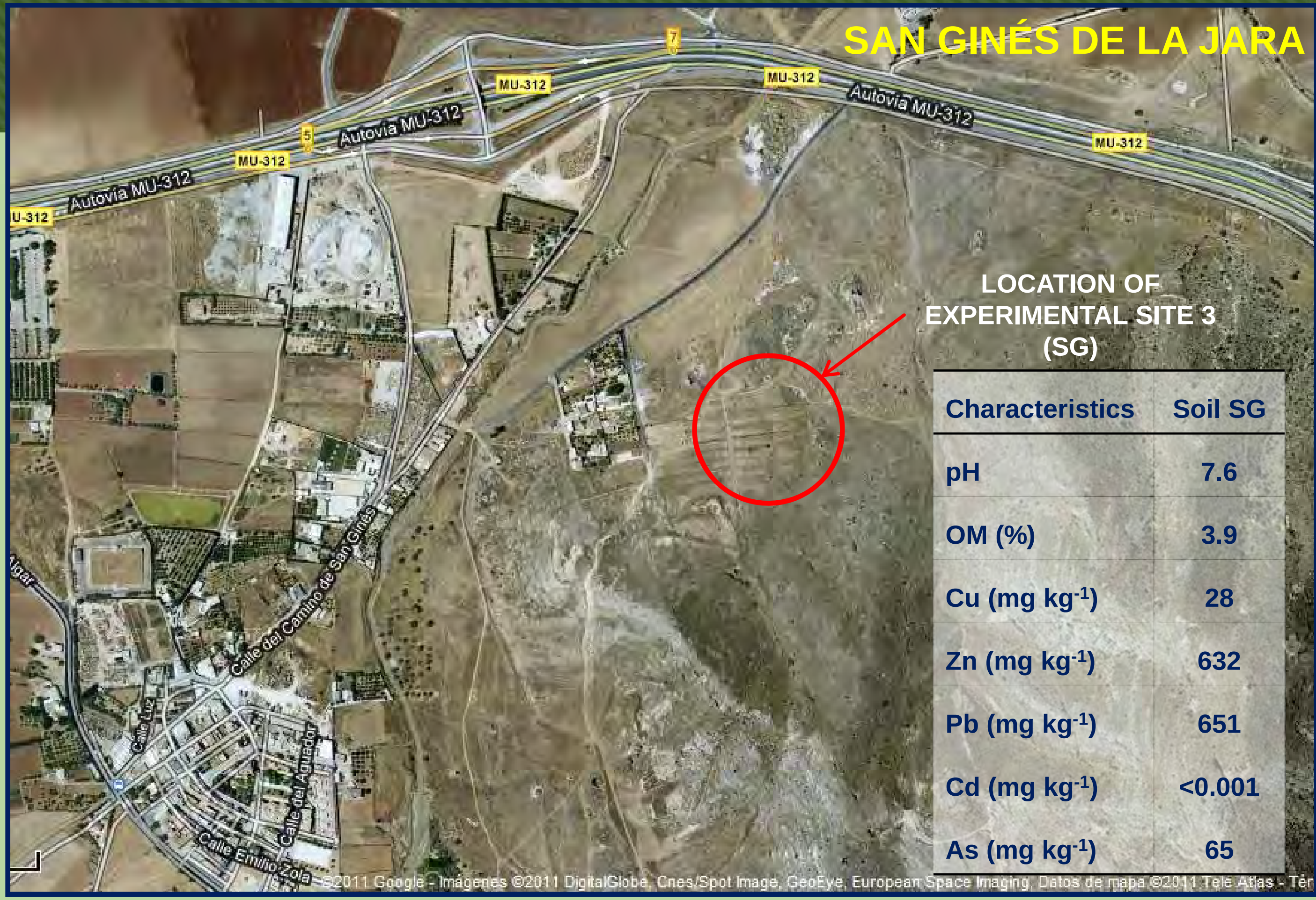
| *L. sativa* | | | |
|---|---|---|---|
| Treatment | G(%) | R(%) | GI(%) |
| Cal-SP | 90 | 67,3 cd | 60,5 bc |
| Cal-A | 94 | 69,1 bcd | 64,9 bc |
| CM-SP | 99 | 92,9 abc | 92 ab |
| CM-A | 99 | 96,9 abc | 95,9 a |
| P-SP | 99 | 96,2 ab | 95,2 a |
| P-A | 98 | 105,8 a | 103,6 a |
| CT | 92 | 51,2 d | 47,3 c |
| ANOVA | ns | ** | ** |

Pardo et al., 2014. *J. Hazard. Mat.* 268, 68-76.

# Case study 2 – CONCLUSIONS

- ✓ Soil toxicity: high salinity, acidic pH and TEs solubility; amendments led to a reduction of their potential associated risks
- ✓ Supply of essential nutrients (pig slurry and compost) promoted a stable vegetation cover, that supposed an extra input of nutrients
- ✓ Both organic amendments in combination with *A. halimus* stimulated the soil microbial communities
- ✓ The combination of compost or pig slurry with *A. halimus*: effective strategy to improve soil health of TEs-contaminated soils under semi-arid conditions

# Case study 3 - Restoration of a TEs contaminated agricultural soil


| Characteristics | Soil SG |
|---|---|
| pH | 7.6 |
| OM (%) | 3.9 |
| Cu (mg kg$^{-1}$) | 28 |
| Zn (mg kg$^{-1}$) | 632 |
| Pb (mg kg$^{-1}$) | 651 |
| Cd (mg kg$^{-1}$) | <0.001 |
| As (mg kg$^{-1}$) | 65 |

# Case study 3 - Restoration of a TEs contaminated agricultural soil

Fertilizer
1.3 t $ha^{-1}$

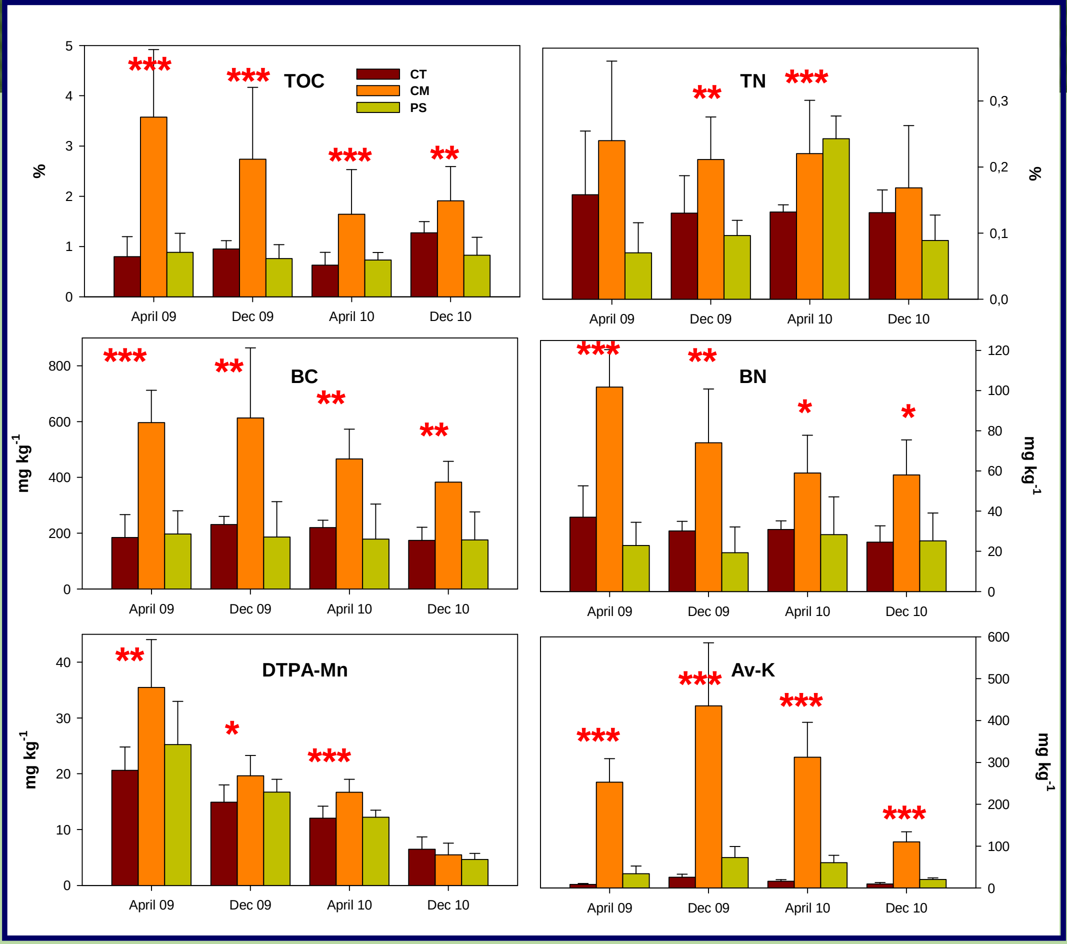
Compost
30 t $ha^{-1}$

# Case study 3 - Restoration of a TEs contaminated agricultural soil

*Atriplex* [illegible]*limus* L.

*Bituminaria bituminosa* L.

# Case study 3 - SOILS: TREATMENT EFFECTS

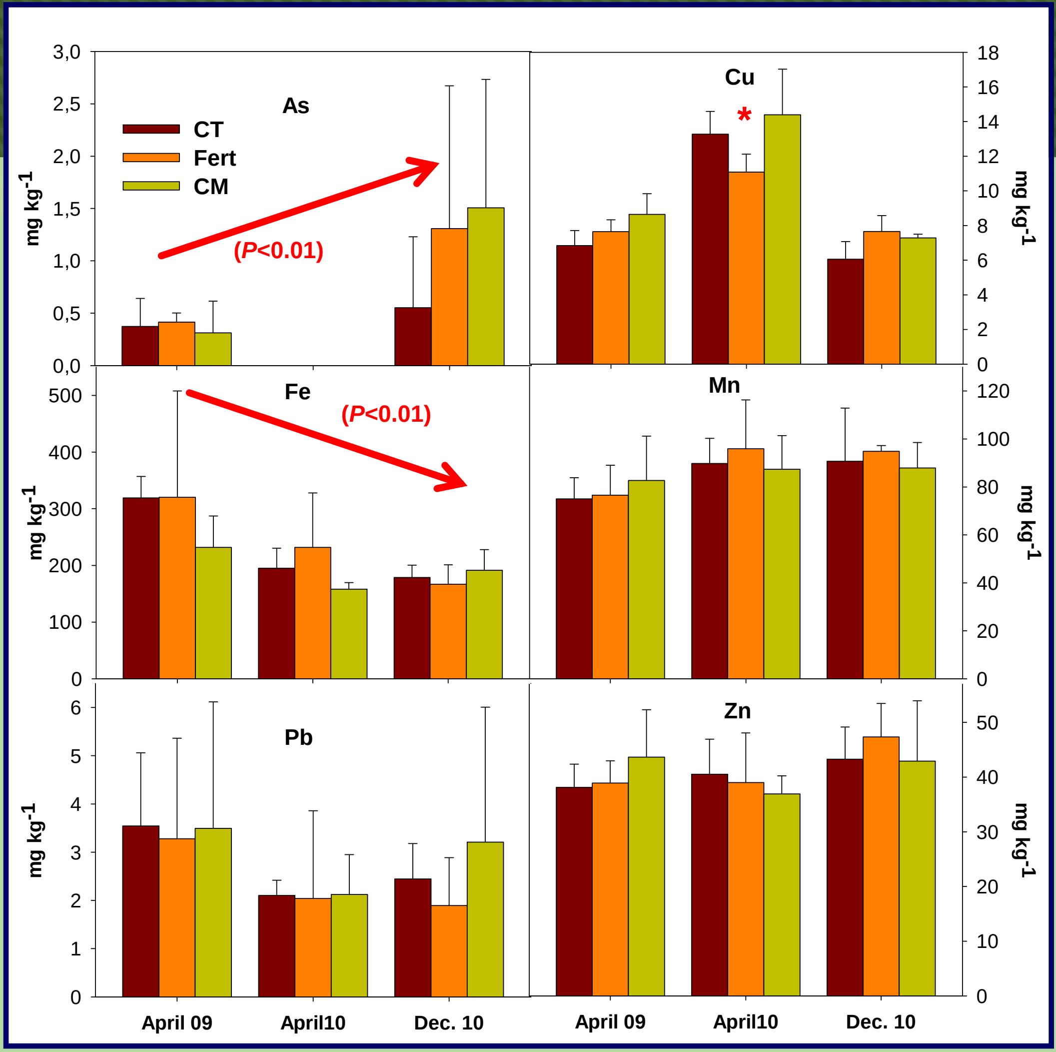



| | Pb | Cd | As | $C_{OT}$ | K | P |
|---|---|---|---|---|---|---|
| $B_C$ | -0,347* | -0,307* | -0,458*** | 0,694*** | 0,771*** | 0,658*** |
| $B_N$ | -0,322* | -0,303* | -0,451*** | 0,758*** | 0,679*** | 0,661*** |

Pearson's Coefficient (r). *: p<0,05; **: p<0,01; ***:p<0,001


Pardo et al., 2014. *Env. Sci. Poll. Res.* 21, 1029-1038.

# Case study 3 - PLANTS (*B. bituminosa*)




Pardo et al., 2014. *Env. Sci. Poll. Res.* 21, 1029-1038.

# Case study 3 - PLANTS (spontaneous vegetation )

**Ecological indexes (number of plant species and individuals)**

# Case study 3 - PLANTS (spontaneous vegetation )

| Familia | Especie |
|---|---|
| Apiaceae | *Eryngium campestre* |
| Asteraceae | *Atractyllis cancellata* |
| | *Carduus bourgeanus* |
| | *Carthannus lanatus* |
| | *Crespis vesicaria subsp haenseleri* |
| | *Dittrichia viscosa* |
| | *Leontodon taraxacoides* |
| | *Phagnalon saxatile* |
| | *Reichardia tingitana* |
| Boraginaceae | *Cynoglossum creticum* |
| | *Echium creticum subsp. coincyanum* |
| | *Echium sabulicolum* |
| Brassicaceae | *Lobularia maritima* |
| Chenopodiaceae | *Atriplex halimus* |
| Cistaceae | *Fumana laevis* |
| Convolvulaceae | *Convolvulus althaeoides* |
| Crassulaceae | *Sedum sediforme* |
| Fabaceae | *Bituminaria bituminosa* |
| | *Coronilla scorpioides* |
| | *Scorpiurus sulcatus* |
| Frankeniaceae | *Frankenia corymbosa* |
| Myrsinaceae | *Anagallis arvensis* |
| Lamiaceae | *Lavandula multifida* |
| | *Thimus hyemalis* |
| Poaceae | *Phalaris brachystachys* |
| | *Stipa capensis* |
| Rubiaceae | *Galium verrucosum* |
| | *Valantia hispida* |
| Xanthorrhoeaceae | *Asphodelus fistulosus* |
| **TOTAL** | **29** |

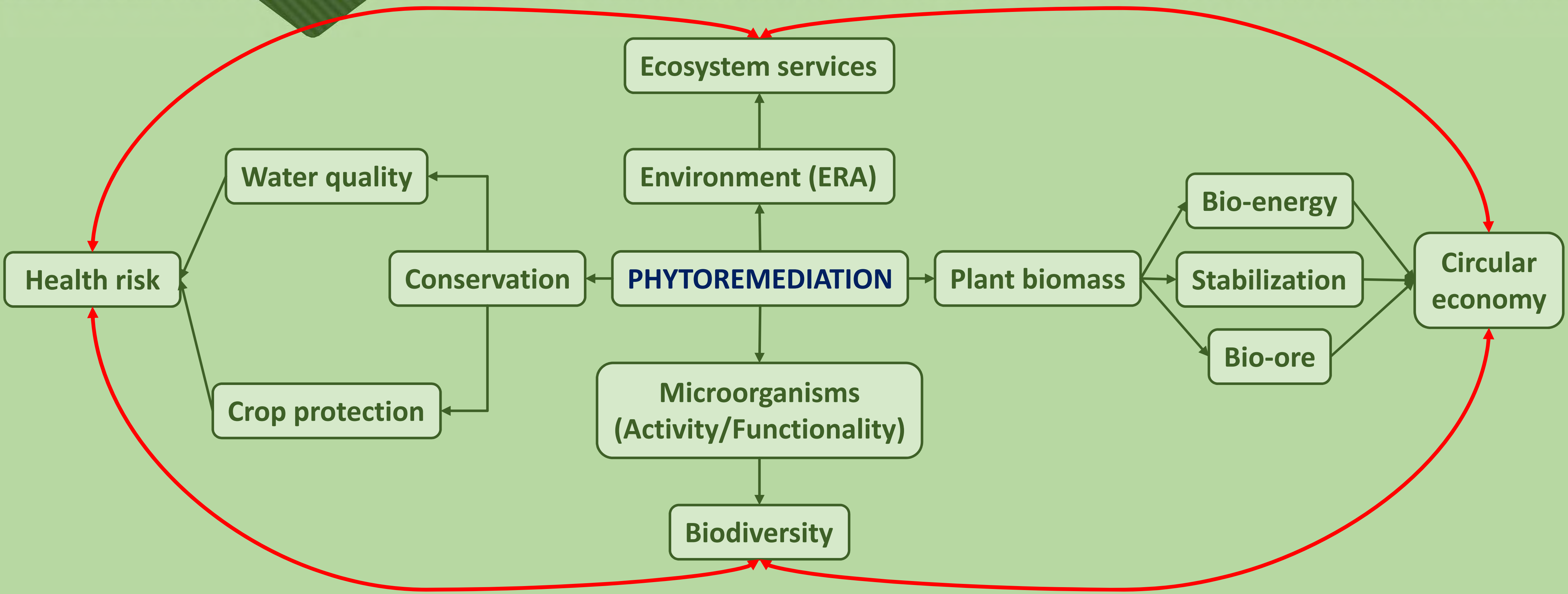
- ✓ 20.1% woody, 79.3% herbaceous
- ✓ No amendment effect on species distribution & abundance
- ✓ Compost > plant cover %

Pardo et al., 2014. *Env. Sci. Poll. Res.* 21, 1029-1038.

# Case study 3 - CONCLUSIONS

- ✓ TEs present mostly in hardly-available forms; amendments application did not alter extractability
- ✓ Long-term supply of essential nutrients (compost): development of the microbial community and improved the plant growth (greater vegetation cover)
- ✓ Compost: useful for phytostabilization of moderately polluted soils, but combination with other species must be studied

# Phytoremediation: Closing the loop



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