Mobility of Metal(loid)s from soil - toward soil pore water - plants and - insects from mining soils amended with biochar

Domenico MORABITO

UNIVERSITE D'ORLEANS | COLLEGIUM Sciences & Techniques Orléans - Bourges - Chartres

INRAE la science pour la vie, l'humain, la terre

INRA USC 1328

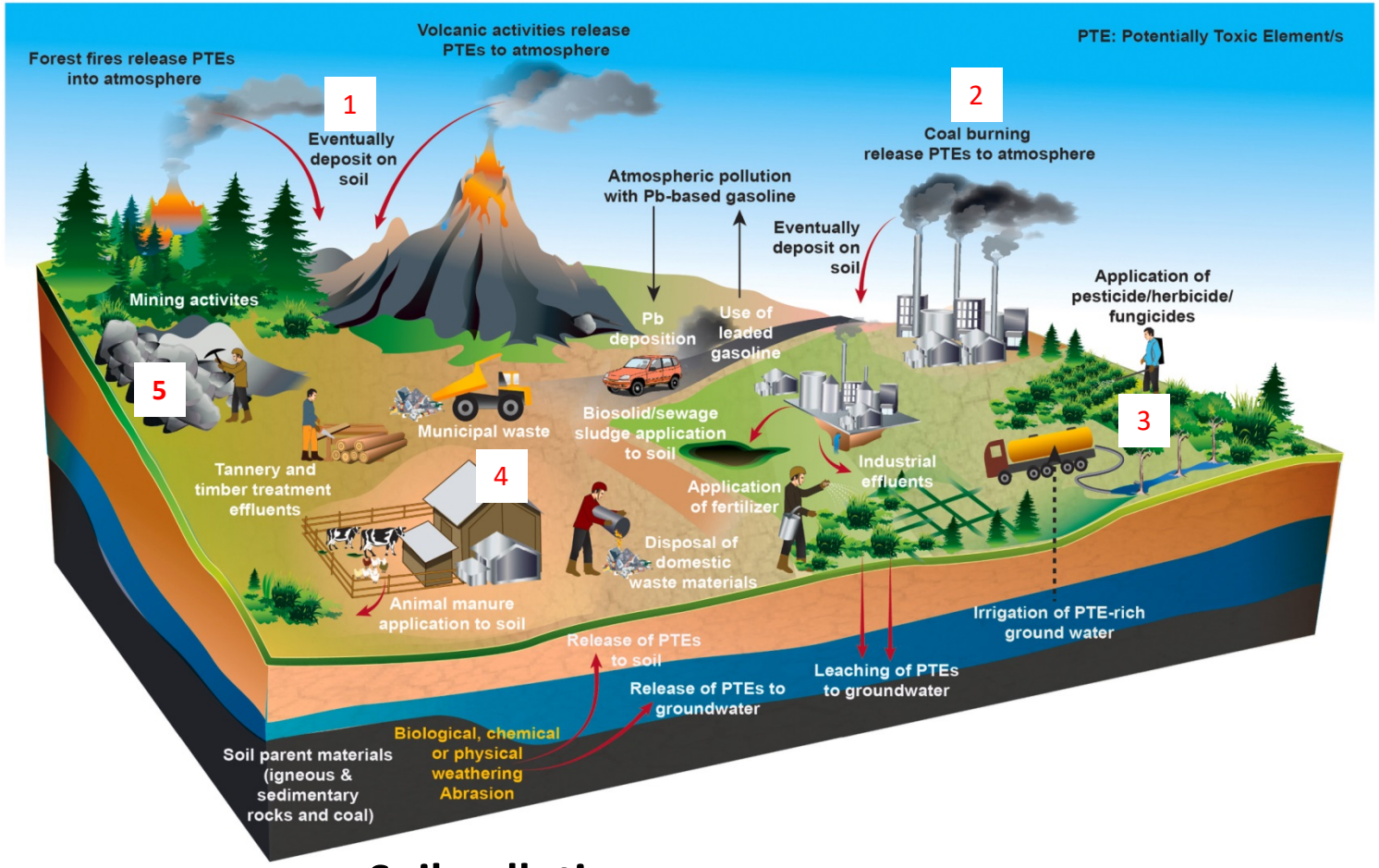
LBLGC Laboratoire de Biologie des Ligneux et Grandes Cultures UPRES EA 1207

V4 Biochar Platform






What are the soil pollution sources?



Soil pollution sources (Palansooriya *et al.* 2020)

- ❖ Natural sources
  - ✓ Volcanic activities (1)
  - ✓ Fires (1)
- ❖ Anthropogenic sources
  - ✓ Industrial actvites (2)
  - ✓ Agriculture (3)
  - ✓ Domestic waste (4)
  - ✓ Mining extraction (5)

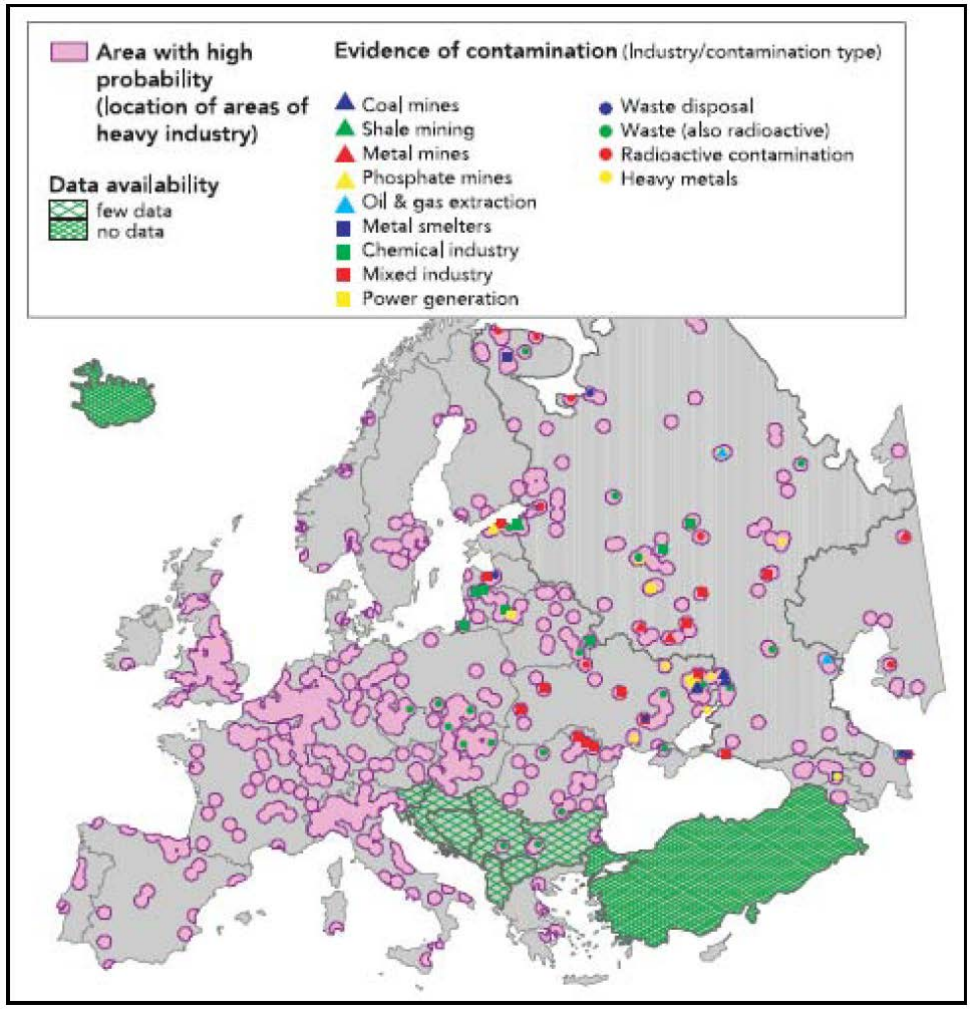
V4 Biochar Platform





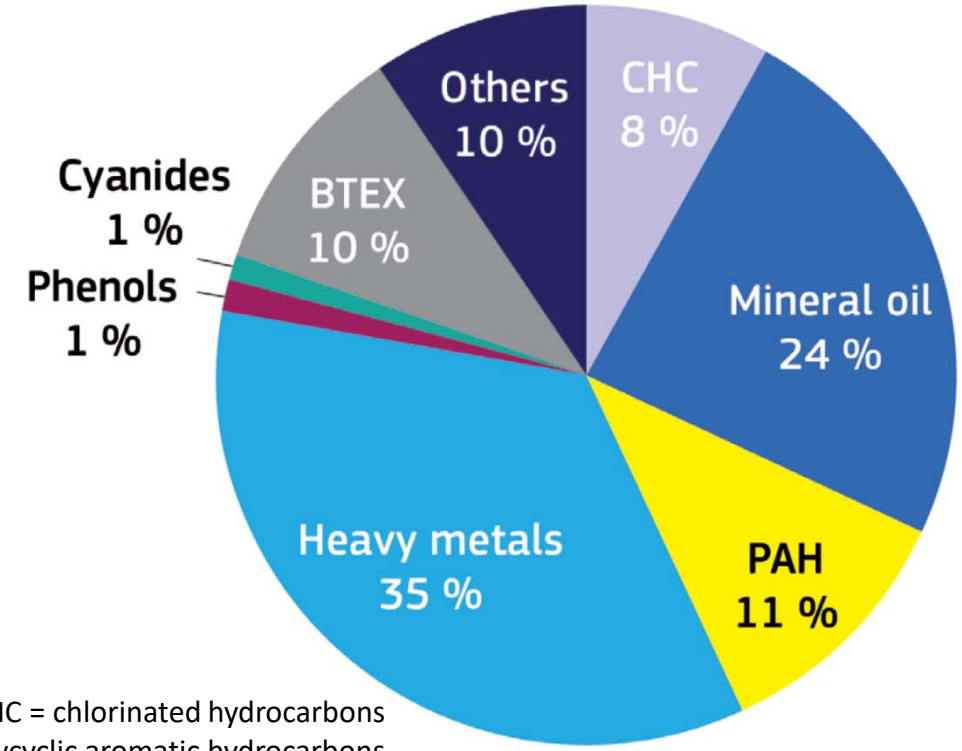

Soil pollution

❖ State of soil pollution in Europe



Van Ginneken *et al.* 2007

❖ What are the main soil pollutants ?



CHC = chlorinated hydrocarbons
PAH = polycyclic aromatic hydrocarbons
BTEX = aromatic hydrocarbons

Van Liedekerke *et al.* 2014

What is soil pollution?

A soil, is considered contaminated when :

-Its chemical state deviates from the normal composition (Kabata-Pendias 2011)

-When it has lost its function (JRC Technical Reports, 2016)

- And lastly when abnormal levels of contaminants become **detrimental** to human health (Rodriguez-Eugenio et al. 2018).

Detrimental effects caused by metal(loid)s depend mainly on their bioavailability?

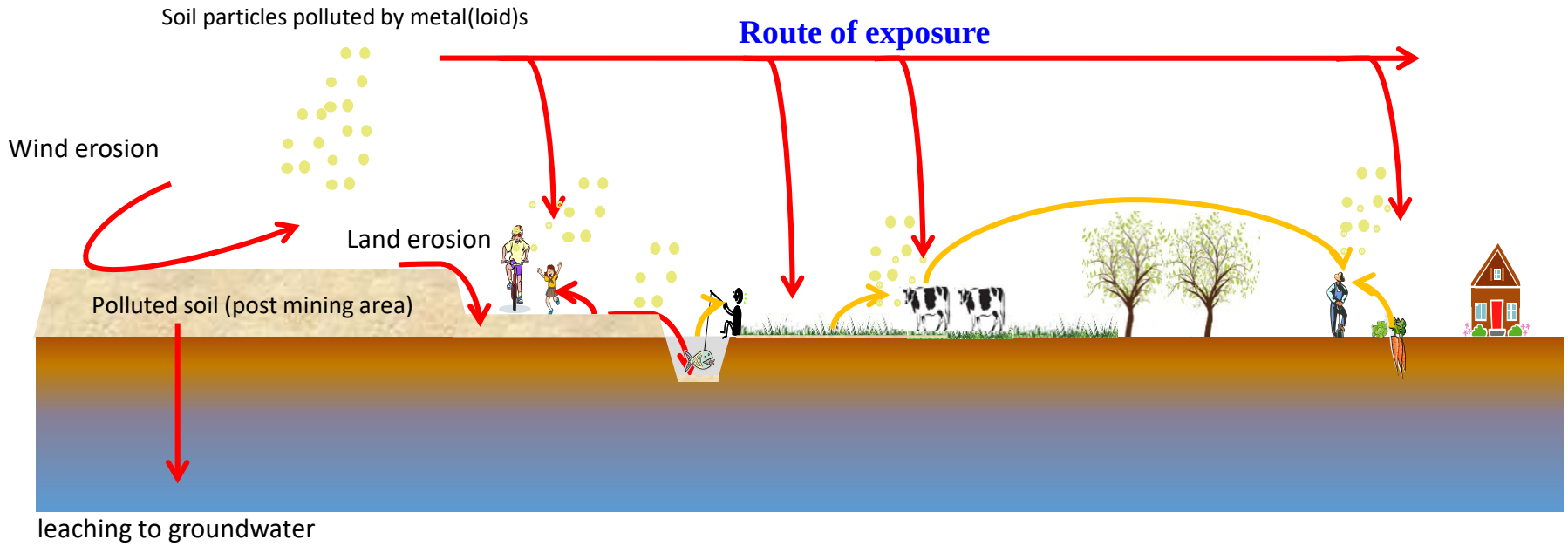
Bioavailability is defined as the fraction of pollutant that, within a given time span, is available or will be made available for its uptake by plants and other organisms (Peijnenburg and Jager 2003)

Bioavailability depends on the physical, chemical and biological properties of the soil (Rodriguez-Eugenio et al. 2018).

In conclusion

- a soil can present very high levels of pollution but this pollution can be poorly available (Because bound to the residual fraction of the soil) ⟹ low risk for the environment
- a soil having a low total metal(loid)s concentration with a high bioavailability will represent a high risk for the environment

What are the pathways of pollutant transfer to the environment?



Sources: concentration of metals and metalloids

Vectors: direct transfer of substances (aerosols, soils, plants)

Vectors: indirect transfer of substances (plants, meat, etc.)

Target groups: biosphere

How to reduce the impact of polluted land on the environment?

Physical remediation

(1) Soil replacement

(3) Electrokinetic remediation

Polluted soil (post mining area)

Surface ground

\+ −

Heavy metals contaminated plume area

High temperature

(4) Thermal treatment

(2) Vitrification

Gong *et al.* 2018

- ✓ Soil improper for vegetation
- ✓ Expensive

Chemical remediation

(5) Chemical immobilization

(6) Solidification/stabilization

M^+ M^{2+} M^+ M^{2+}

M: Heavy metal

Soil solution

Immobilization

Mobilization

(7) Soil washing

M M M

Soil particles

Biological remediation

(8) Phytoremediation

Phytovolatilization

Phytoextraction

Translocation

Phytostabilization

(9) Microbial remediation

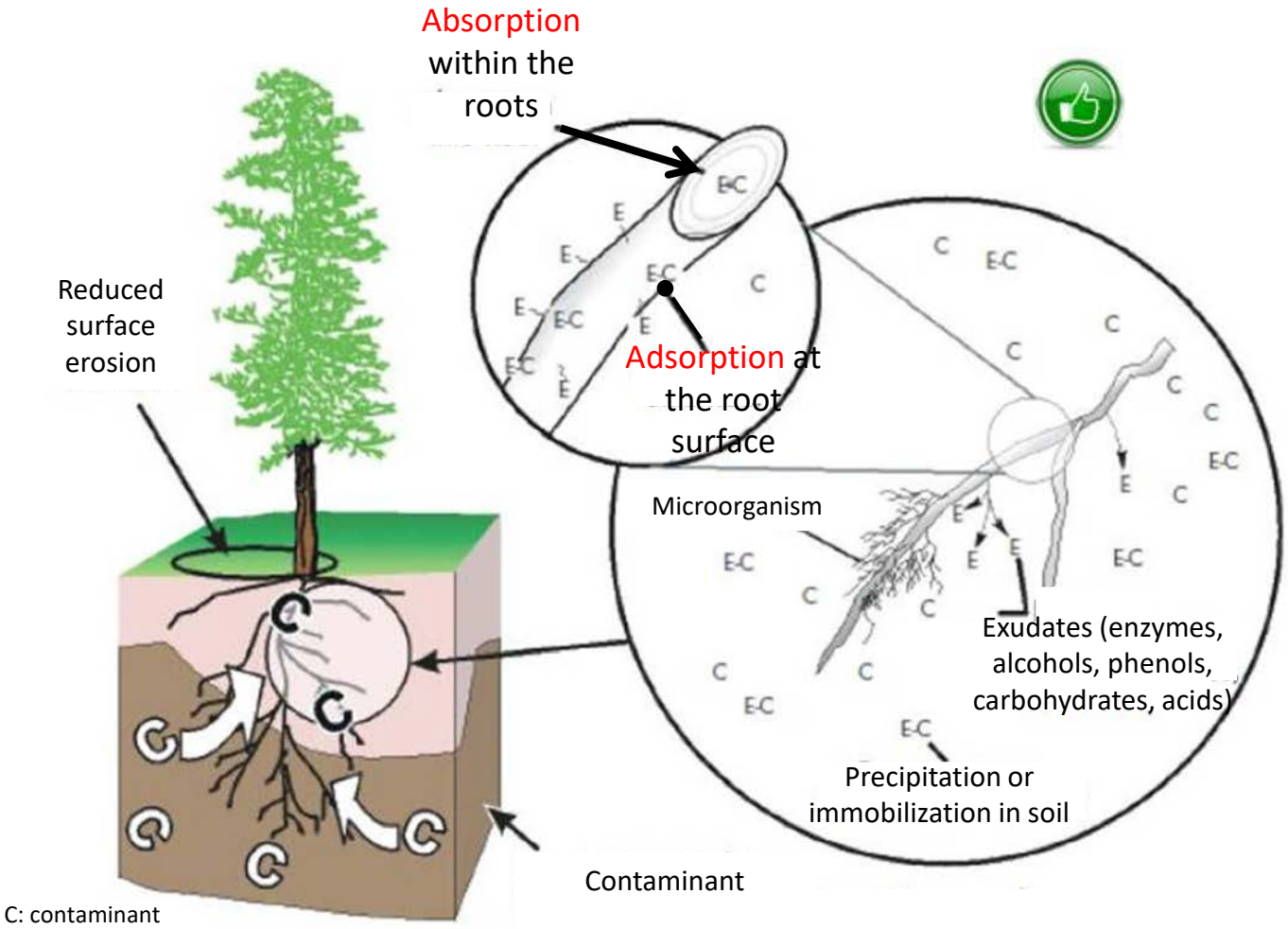
Metal immobilization

Metal mobilization

(10) Microbial assisted phytoremediation

- ✓ Environmentaly friendly
- ✓ Accepted by the citizens
- ✓ Lower cost
- ✓ Long period

What are the rhizospheric mechanisms of metal immobilization in the phytostabilization process?



Adapted from Van Slycken (2011)

It is an environmentally-friendly technology to economically remediate mining soil containing important concentration of metal(loid)s using plants (**Phytostabilization**)

The main point consist to stabilize the pollutants in the soil and to allow the growth of plants
Sometimes the soil is heavily polluted and poor from an agronomic point of view
Need to use one or more amendments to improve the characteristics of the soil
Aided or assisted phytostabilization (**Biochar**)

Considering that we produce a valuable biomass

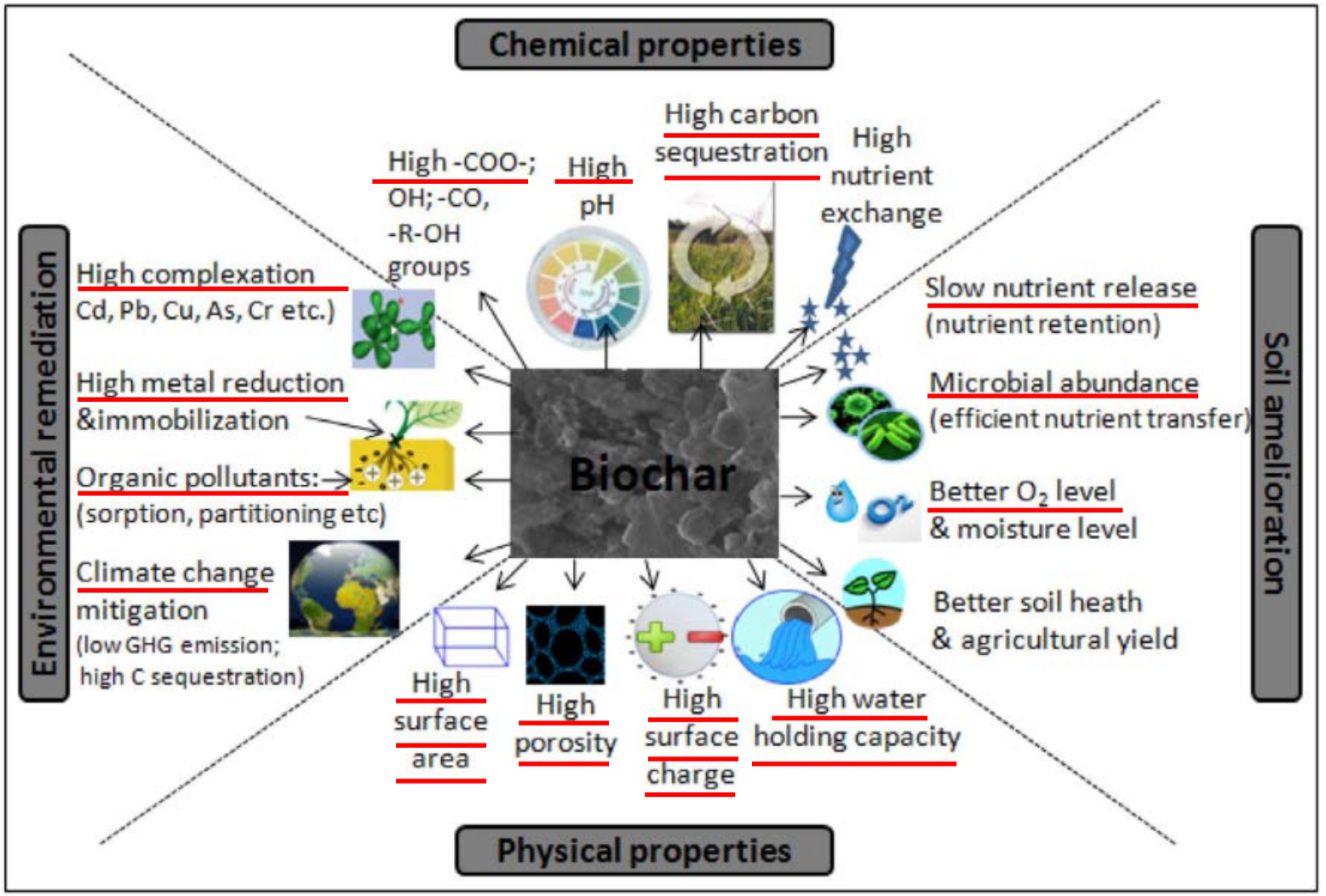
PHYTOMANAGEMENT

V4 Biochar Platform






What are the advantages of biochar in assisted phytostabilization?

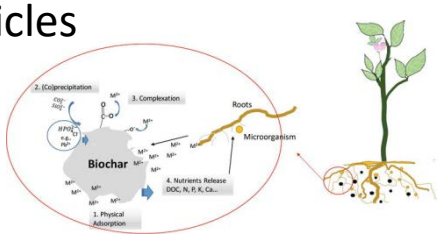


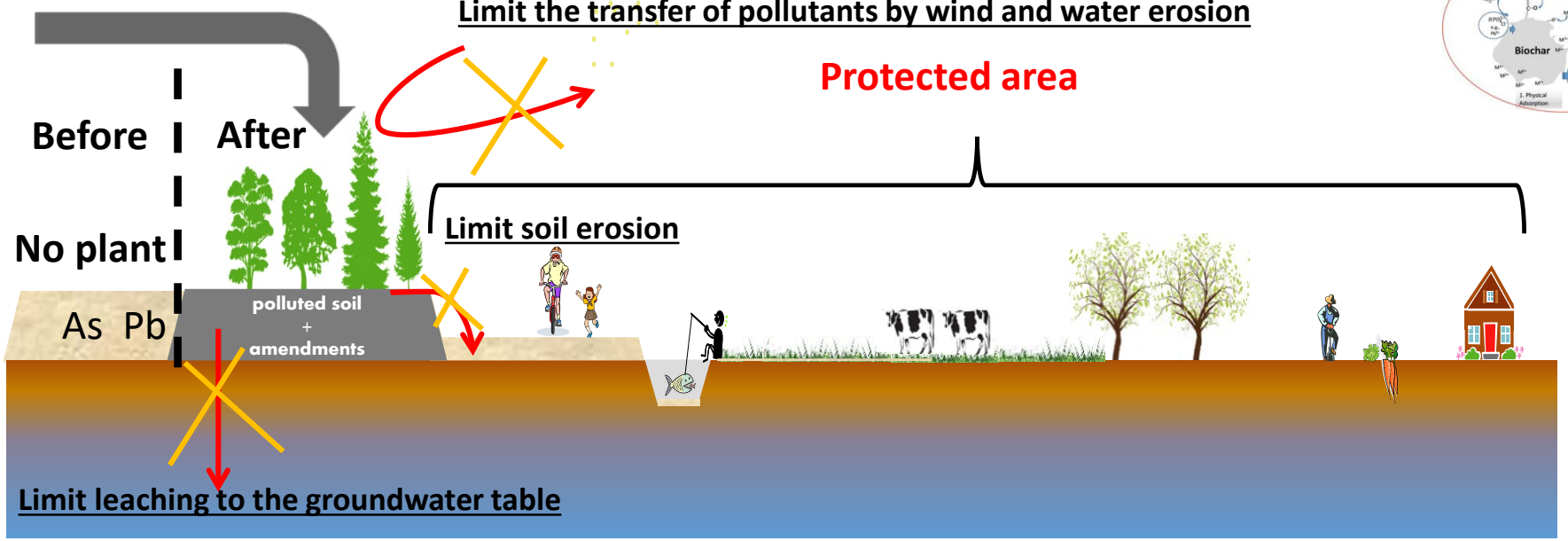
V4 Biochar Platform





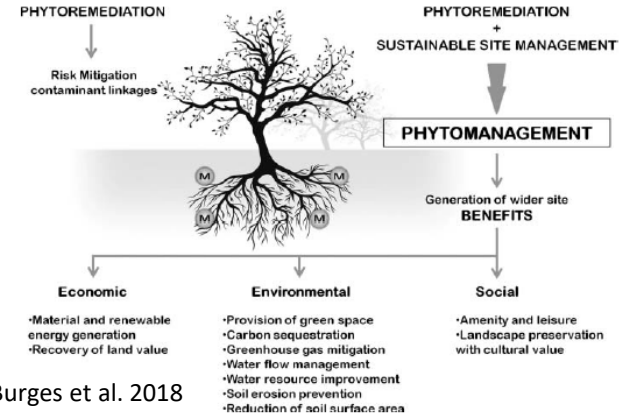

Addition of amendments to the soil ➡ Stabilize pollutants : on the amendment and on the soil particles





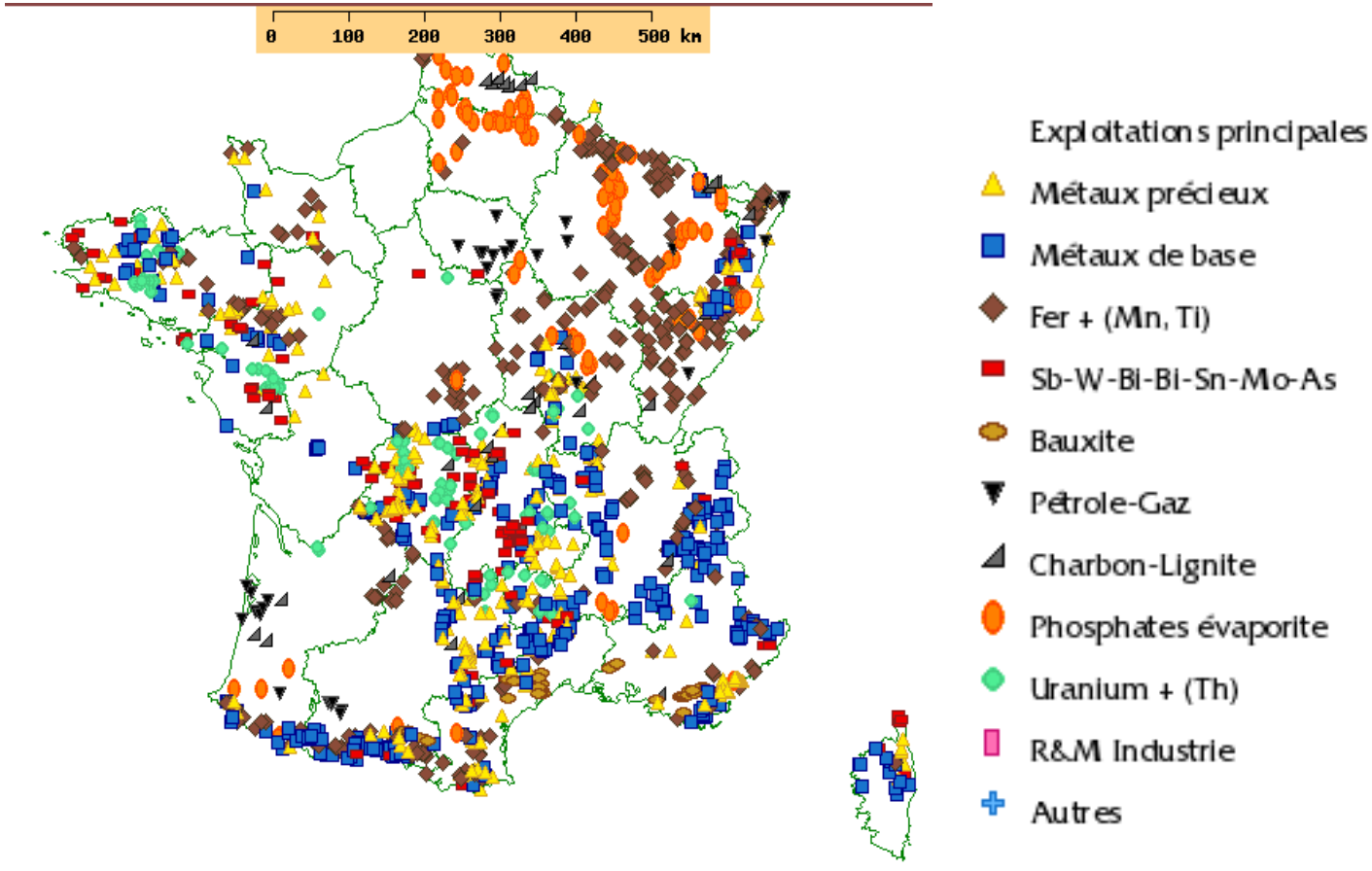
❖ When added to a soil it :

-Increase soil water holding capacity
-Provide nutrients
-Will decrease pollutant concentration in soil pore water
-Will make pollutant not phytoavailable
-Will increase soil microorganisms diversity and quantity



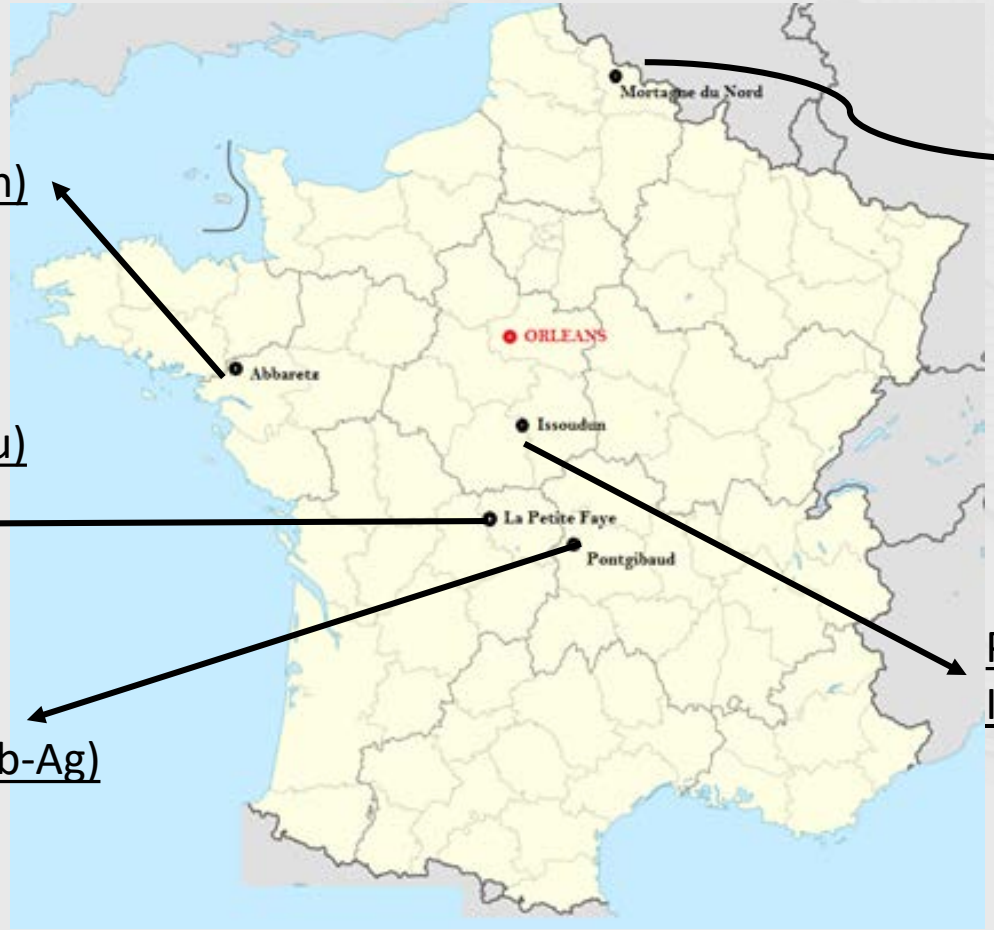
Aritz Burges et al. 2018

- French mining sites monitored by the French Prevention and Mine Safety Department : 1800



Poluted sites studied in France

Abbaretz mine (Sn)



Post-industrial area (metal smelter)
Mortagne du Nord

La petite Faye mine (Au)

Post-industrail area (chemical factory)
Issoudun

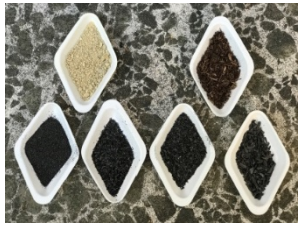
Pontgibaud mine (Pb-Ag)

Presentation of the experiments carried out

Selection of biochars
Laboratory test

Field test

Metal(loid)s transfer
soil-plant-aphids



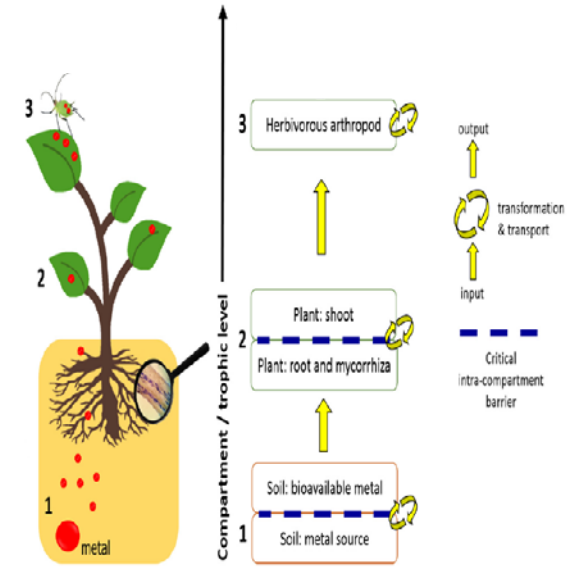
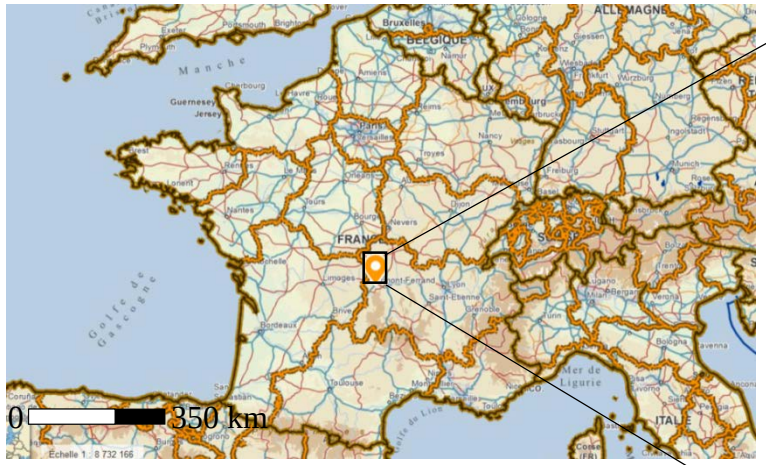
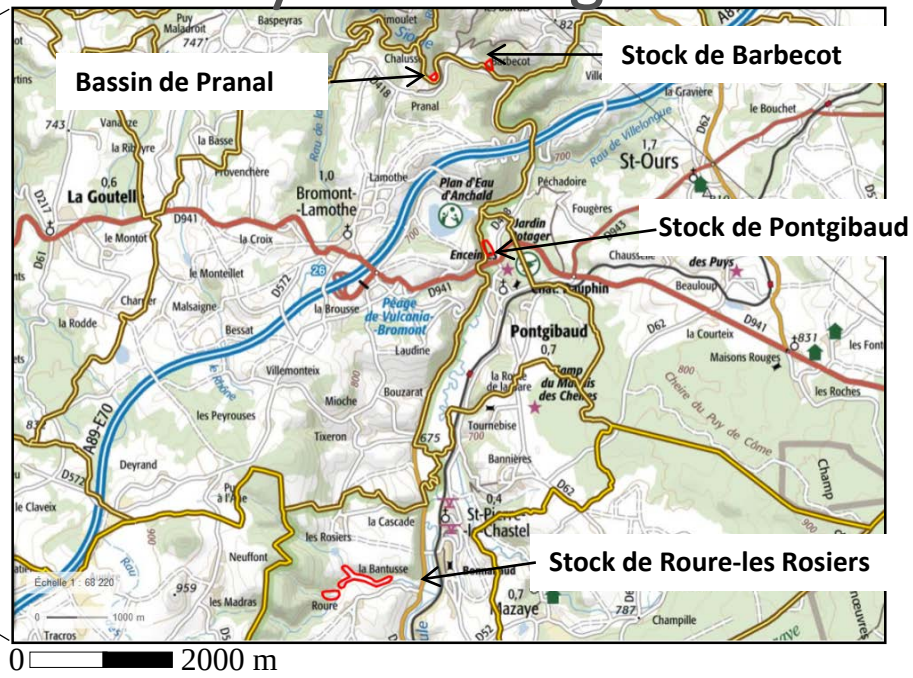


Fig. 1. Conceptual compartmentalised model system for transfer of metals in a linear pathway from basal abiotic (soil) sources to higher biotic trophic levels in the soil-plant-arthropod system. Red circles represent metals and numbers 1 to 4 represent a trophic compartment.

Location and characteristics of the study site Pontgibaud





- Old silver lead mine
- Dating from the 19th century

Final abandonment of the site in 1947

❖ **Main pollution Pb (11 453 mg.kg^{-1})** and **As (539 mg.kg^{-1})**

- Surface : 15 ha (volume of residues 87200 m^3)
- Rainfall 1000 mm
- Temperatures ranging from 40°C in summer to -20°C in winter.
- Rather sandy texture.

Selection of biochars
Laboratory test

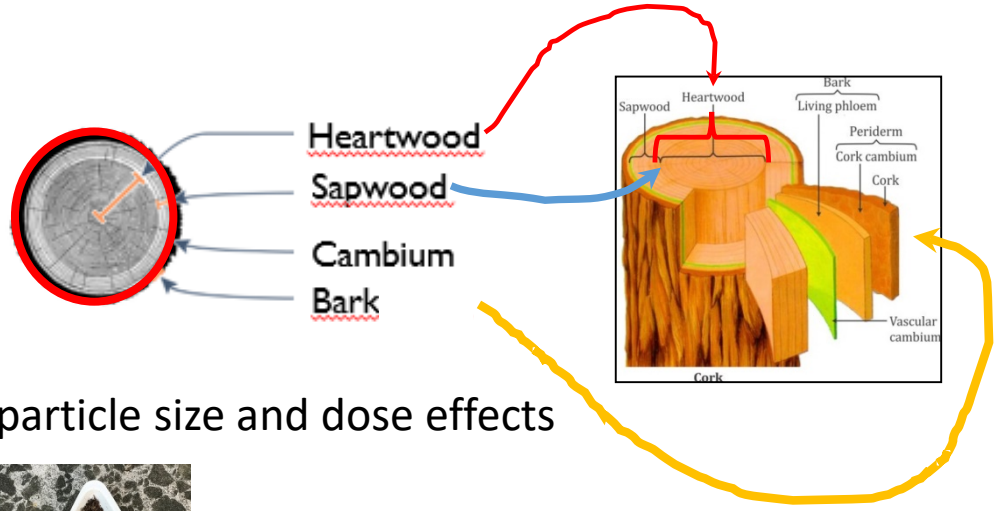
To found the best conditions to rehabilitate the soil and to allow plant growth adding biochar (Stabilization of metal(loid)s in soil)

- Plant biomass production
- Availability of metal(loid)s in soil pore water
- Plant metal(loid)s content

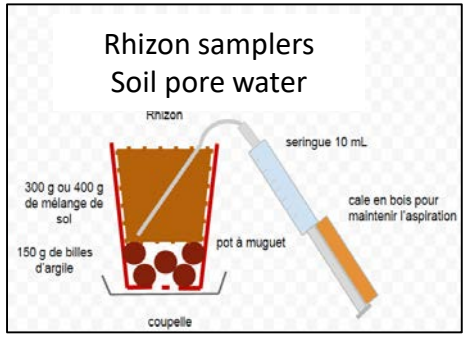
❖ Evaluation of the feedstock effect

Hard wood | Light wood | Pine wood

❖ Evaluation of the tissue effect inside one feedstock



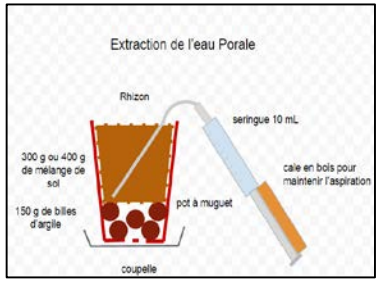
Phytotoxicity test
using *Phaseolus vulgaris*

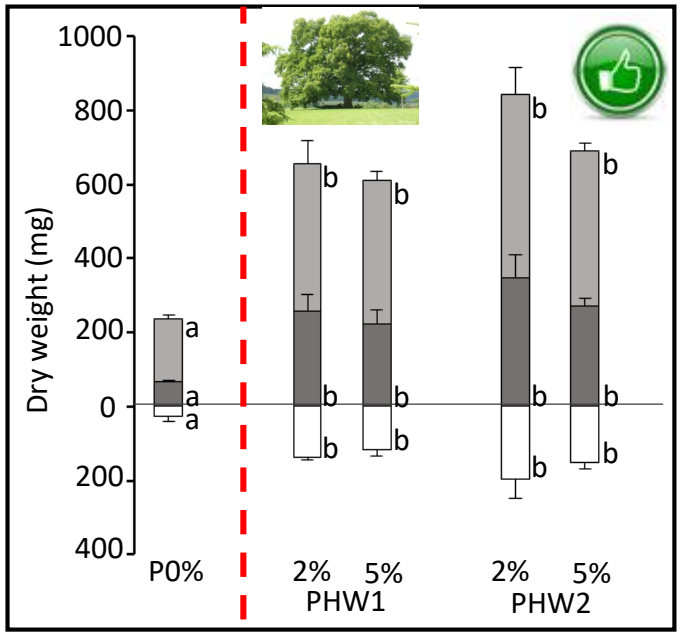


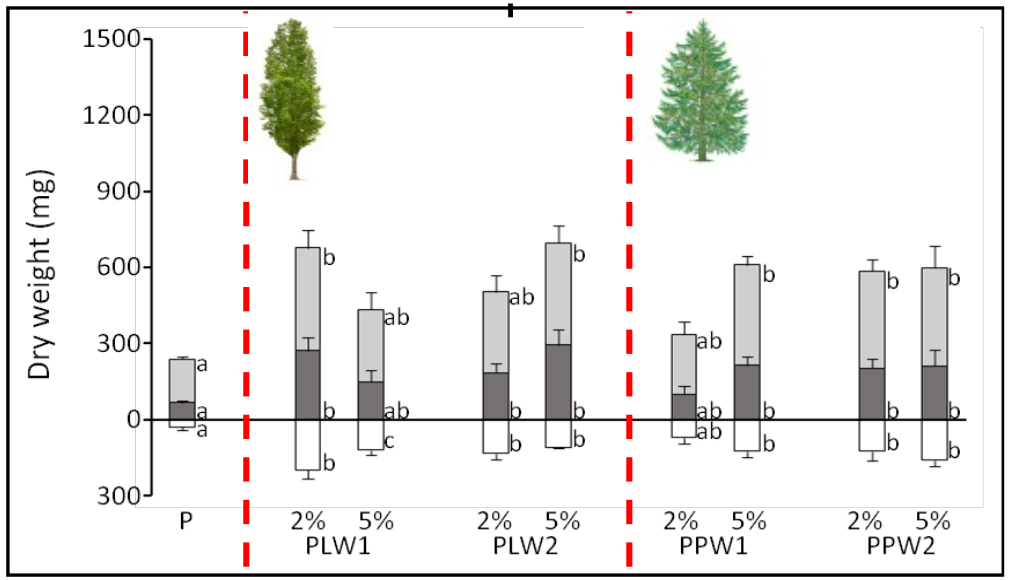
❖ Evaluation of the particle size and dose effects

Preliminary laboratory testings

- Evaluation of the feedstock effect







Treatment	SPW [Pb] decrease
PHW1 – 2%	98 %
PHW1 – 5%	98 %
PHW2 – 2%	88 %
PHW2 – 5%	97 %
PLW1 – 2%	94 %
PLW1 – 5%	98 %
PLW2 – 2%	97 %
PLW2 – 5%	99 %
PPW1 – 2%	81 %
PPW1 – 5%	89 %
PPW2 – 2%	60 %
PPW2 – 5%	77 %

Salix viminalis dry weight (g) after 45 days of growth on Pontgibaud amended with biochars made from hardwood (HW), lightwood (LW) and pinewood (PW).

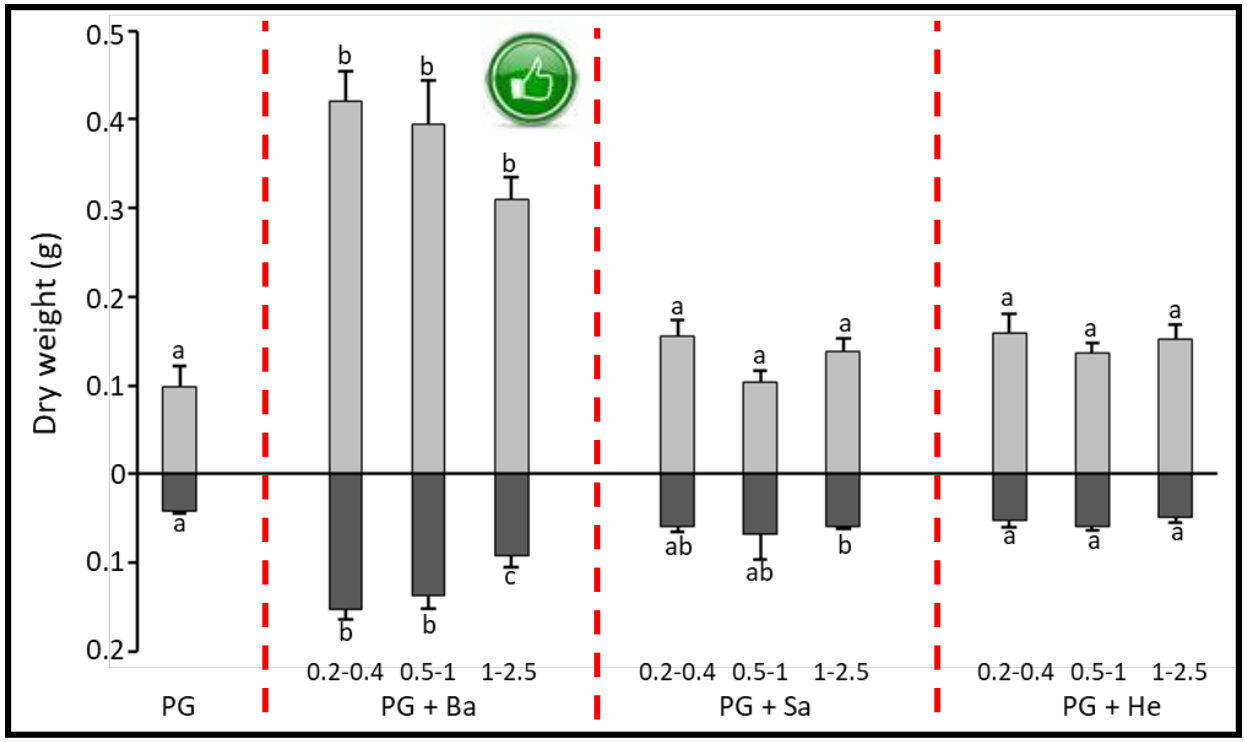
Leaves
Stems
Roots

➔ **Selection of the Hardwood feedstock**

Lebrun et al. 2018 (JSS, Chemosphere)

Preliminary laboratory testings

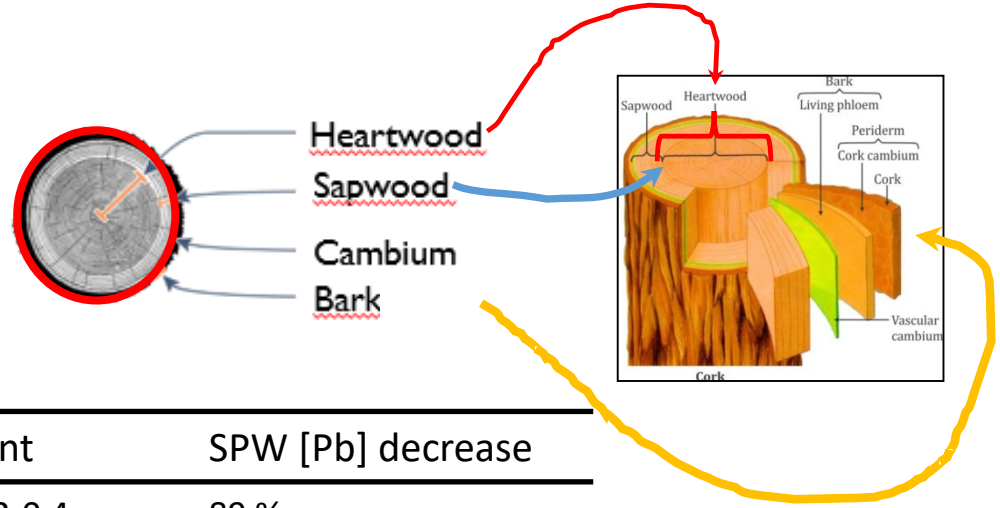
❖ Evaluation of the tissue effect inside one feedstock



Phaseolus vulgaris dry weight (g) after 15 days of growth on Pontgibaud amended with biochars made from bark (Ba), sapwood (Sa) and heartwood (He).

Aerial part

Rots



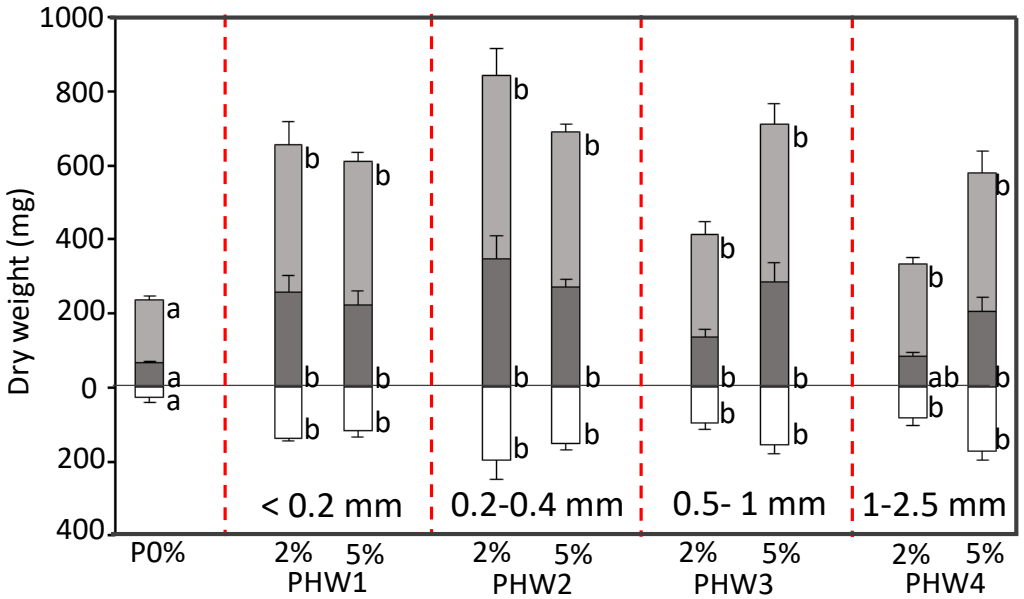
Treatment	SPW [Pb] decrease
PG+Ba 0.2-0.4	89 %
PG+Ba 0.5-1	90 %
PG+Ba 1-2.5	68 %
PG+Sa 0.2-0.4	51 %
PG+Sa 0.5-1	44 %
PG+Sa 1-2.5	41 %
PG+He 0.2-0.4	38 %
PG+He 0.5-1	34 %
PG+He 1-2.5	28 %

➔ **Biochars made from Bark showed better effects**

Lebrun et al. 2020 (STOTEN)

Preliminary laboratory testings

❖ Evaluation of the particle size and dose effects



Salix viminalis dry weight (g) after 45 days of growth on Pontgibaud amended with biochars made from hardwood (HW) and harboring different particle sizes (HW1 = < 0.2 mm, HW2 = 0.2-0.4 mm, HW3 = 0.5-1 mm, HW4 = 1-2.5 mm)

Leaves
Stems
Roots

Treatment	SPW [Pb] decrease (T0)		SPW [Pb] decrease (T45)
PHW1 – 2%	98 %	< 0.2 mm	98 %
PHW1 – 5%	98 %		98 %
PHW2 – 2%	88 %	0.2-0.4 mm	97 %
PHW2 – 5%	97 %		97 %
PHW3 – 2%	29 %	0.5- 1 mm	86 %
PHW3 – 5%	65 %		96 %
PHW4 – 2%	35 %	1-2.5 mm	38 %
PHW4 – 5%	32 %		95 %

Lebrun et al. 2018 (JSS)

➔ **Biochars with smaller particle sizes are more efficient**

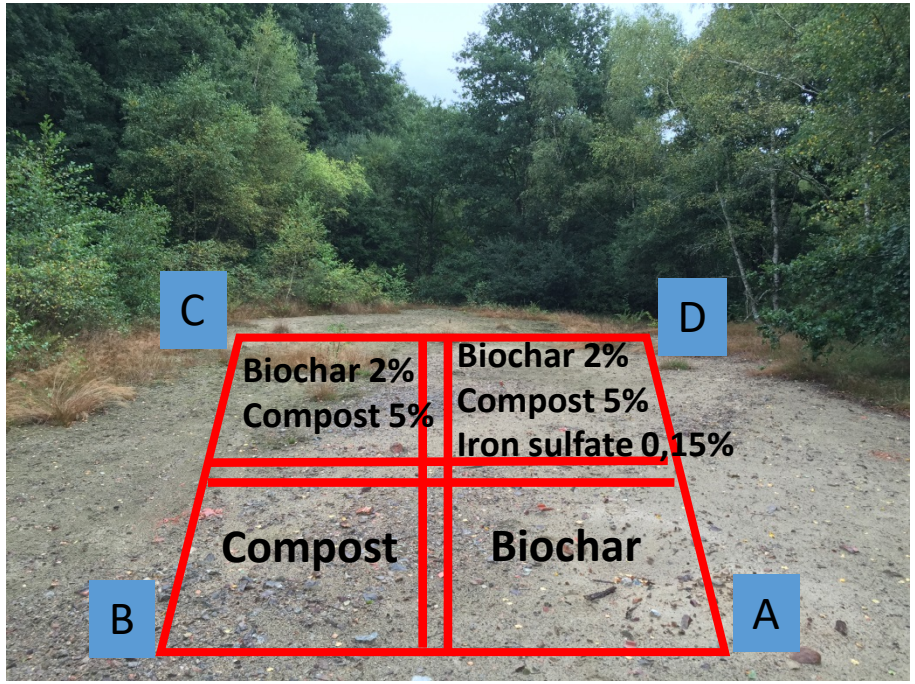
➔ **Biochars with coarser particle sizes make longer time to be efficient**

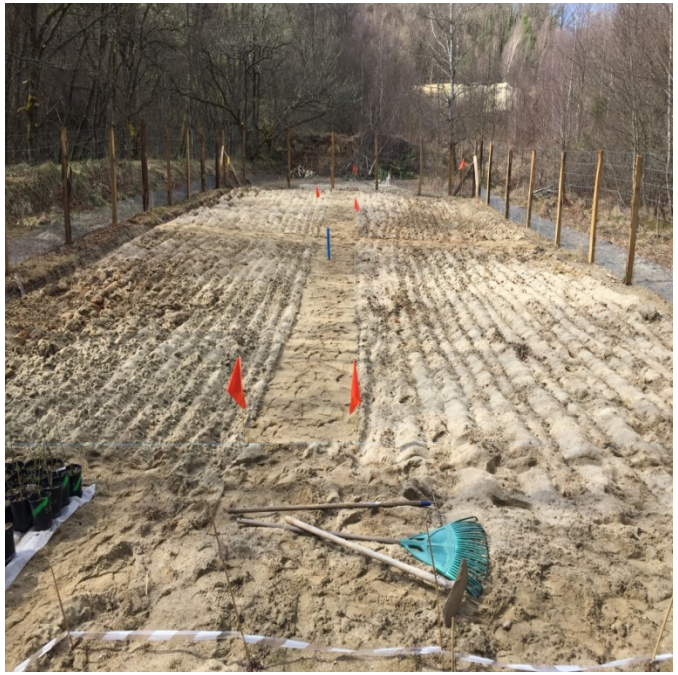
Field test

The aim:
to allow plant growth on a sterile and polluted soil

In order to limit the transfer of pollutants (metals and metalloids) to the environment?

Polluted soil tests, Pontgibaud mine area divided in 4 plots



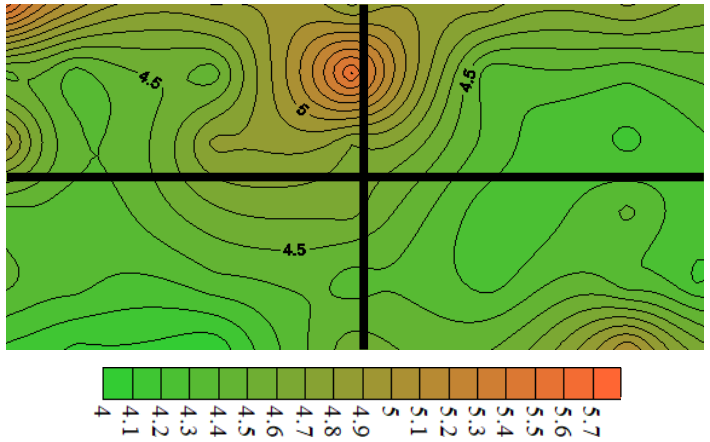


Biochar 2%
to stabilize the lead

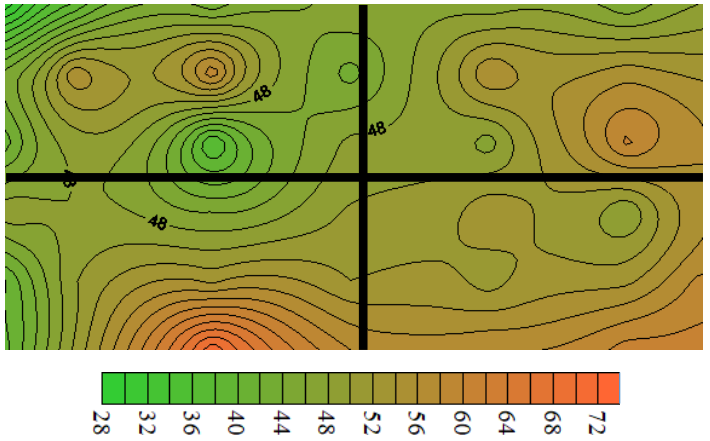
Compost 5%
to improve the agronomic quality of the soil

Iron sulfate 0,15 %
to stabilize arsenic

Mapping of pH, EC, [Pb] and [As] values of the plot at initial state before amendments

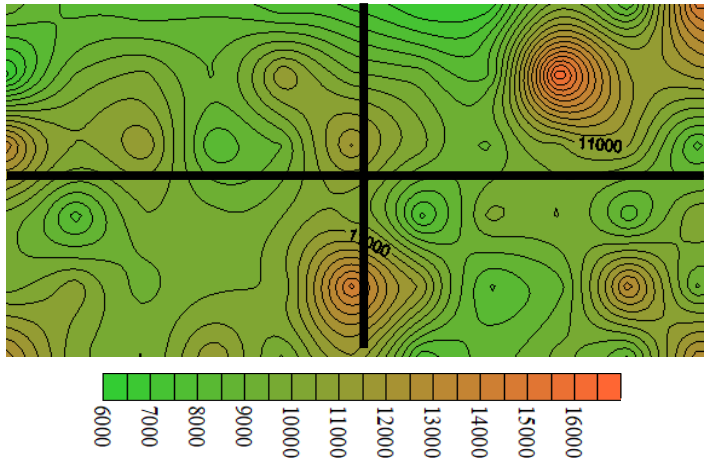


pH 4 - 5,8

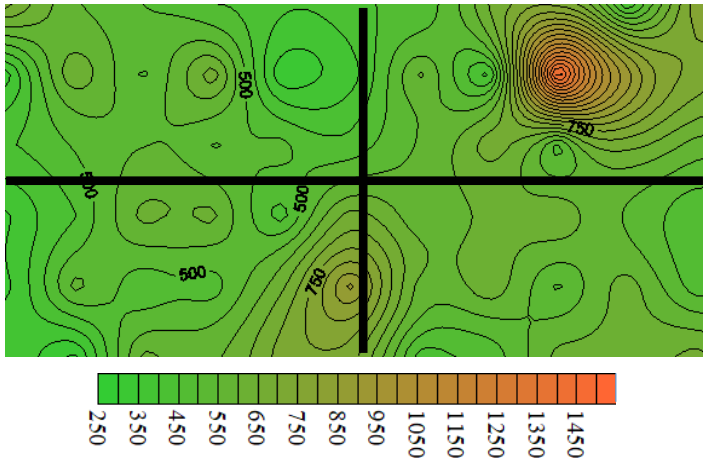


EC 28 - 74 µS.cm^{-1}

compost	Biochar +compost
biochar	Biochar +compost + iron sulfate



[Pb] 6000 - 17000 mg/kg



[As] 250 - 1550 mg/kg

- High metal content
- low pH
- Very low OM
- Strong drainage
- No vegetation

V4 Biochar Platform

V4 Biochar Platform






1month after amendment and plantation of salix trees

S.Al: *S.alba*

S.Vi: *S.viminalis*

S.Tr*: S.triandra*

S.Pu: *S.purpurea*

V4 Biochar Platform






After 4 months

V4 Biochar Platform



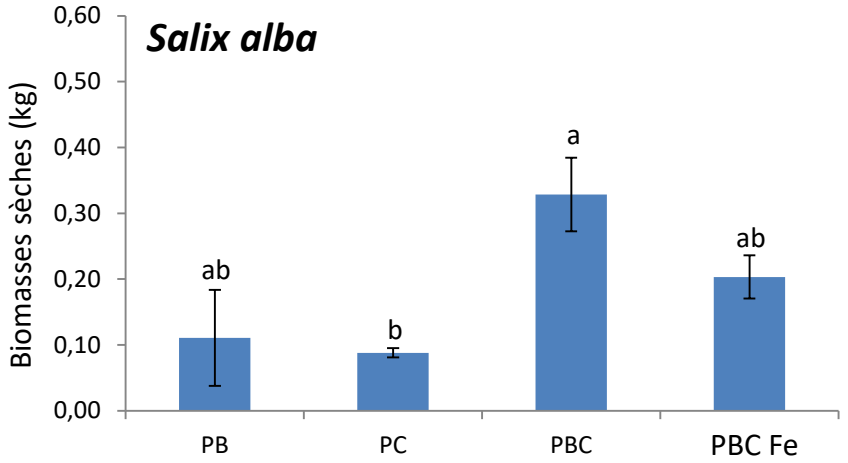


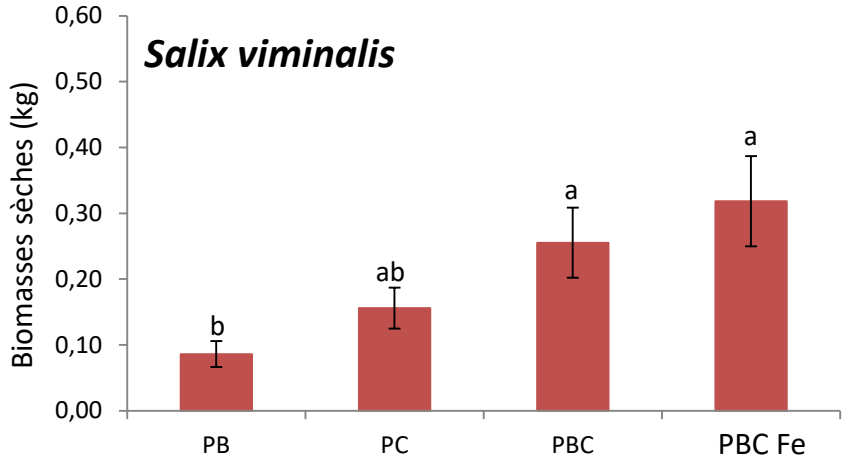

After 6 months

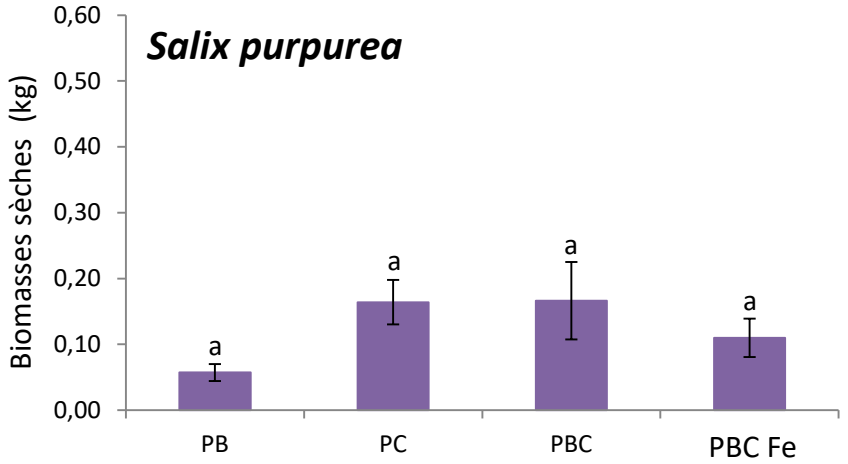
After 18 months

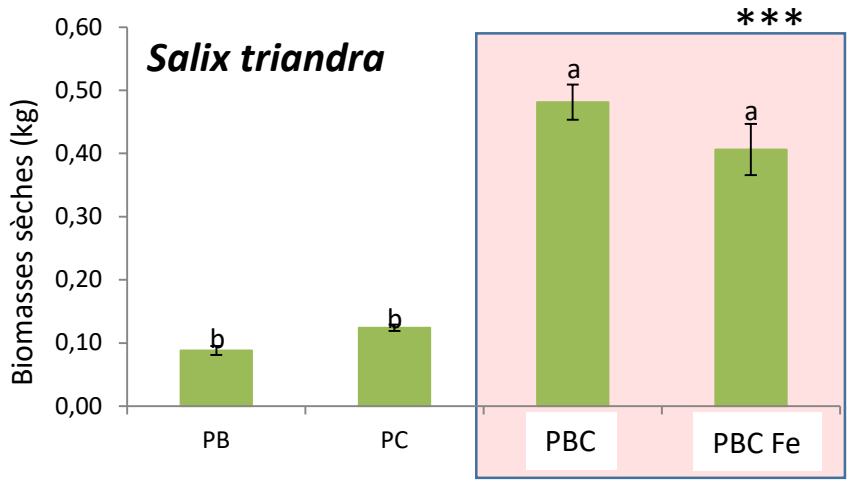
biochar + compost + iron sulfate

Biomass production after 2 years



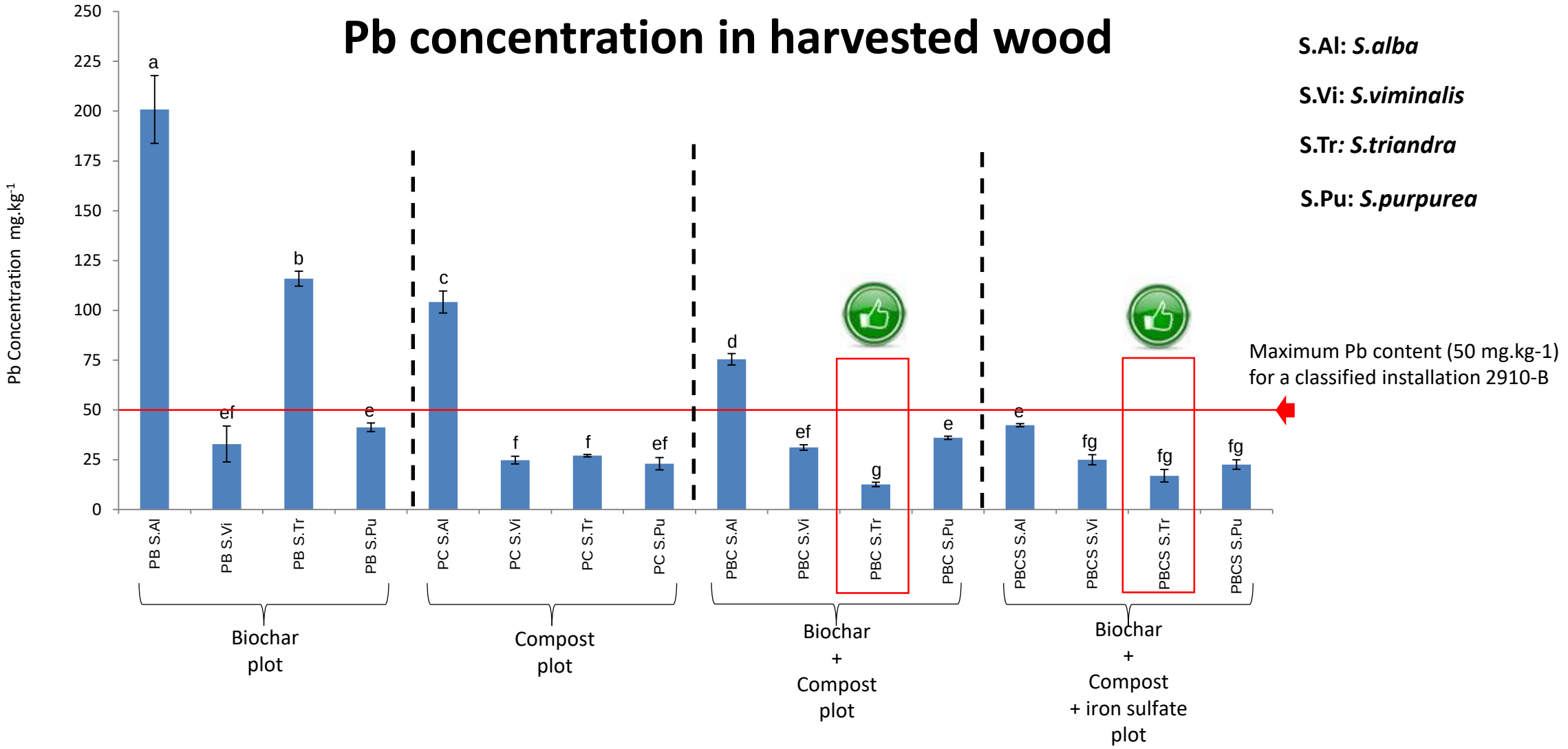






PB : biochar 2%
PC : compost 5%
PBC : compost 5% + biochar 2%
PBCS : compost 5% + biochar 2% + iron sulfate 0,15%

Pb concentration in harvested wood



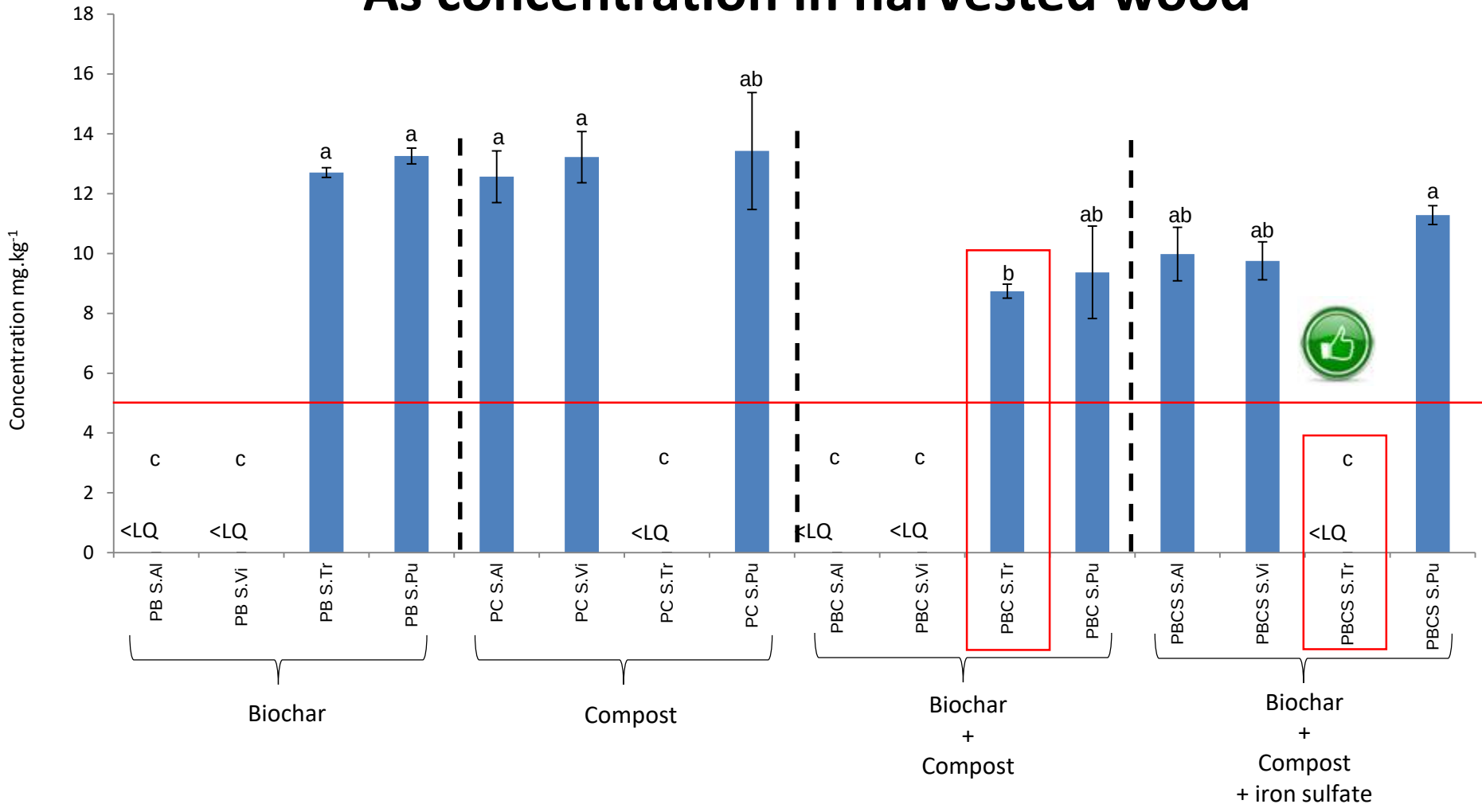
S.Al: ***S.alba***

S.Vi: ***S.viminalis***

S.Tr: ***S.triandra***

S.Pu: ***S.purpurea***

As concentration in harvested wood



S.Al: *S.alba*

S.Vi: *S.viminalis*

S.Tr*: S.triandra*

S.Pu: *S.purpurea*

Maximum As content (5 mg.kg-1) for a classified installation 2910-B

- **Salix purpurea possède [As] la plus élevée**

V4 Biochar Platform

Conclusion

Before implementing a assisted phytostabilization strategy on a polluted site it is necessary to carry out :

-Laboratory tests to define the best biochar according to the metal present in the soil.
-Check that the pollutant is immobilized
-Efficient plant growth
-No translocation of the metal into the aerial part of the plants.

V4 Biochar Platform






Metal(loid)s transfer soil-plant-aphids

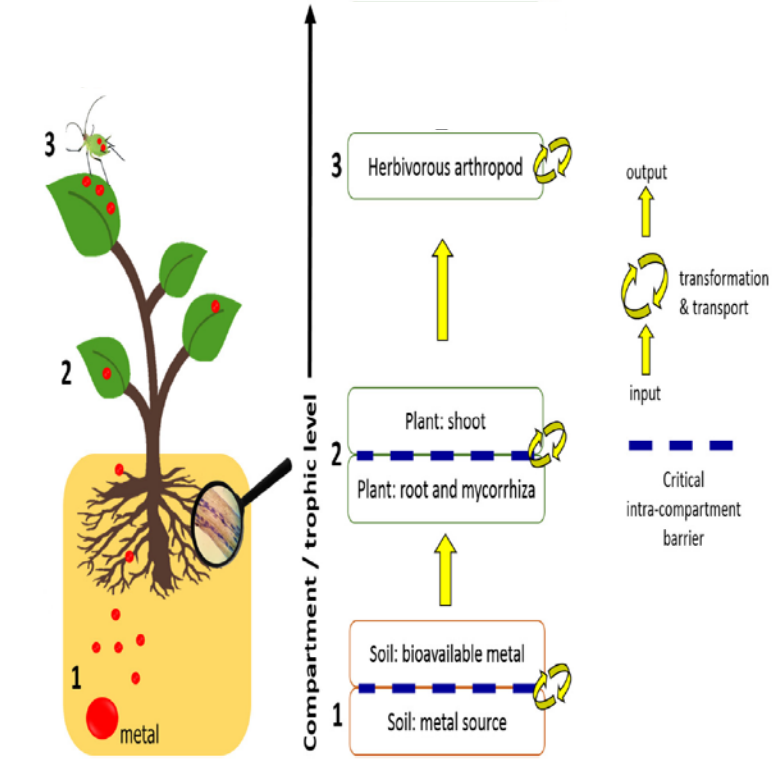
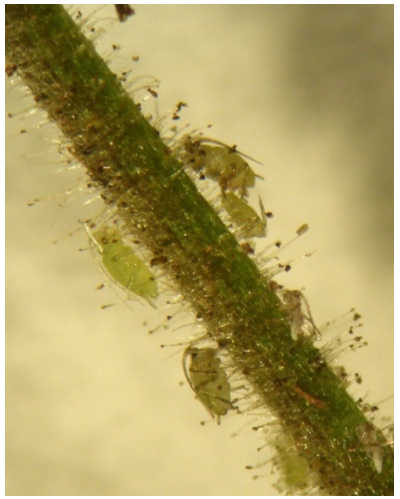
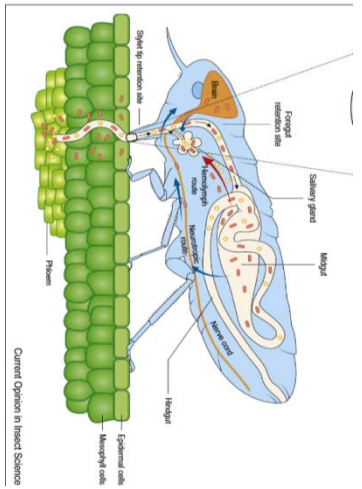


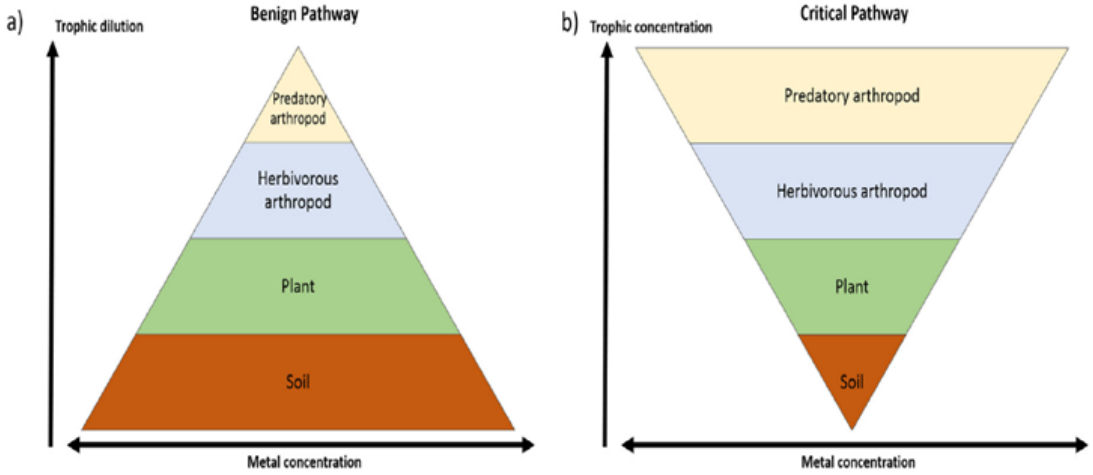
Fig. 1. Conceptual compartmentalised model system for transfer of metals in a linear pathway from basal abiotic (soil) sources to higher biotic trophic levels in the soil-plant-arthropod system. Red circles represent metals and numbers 1 to 4 represent a trophic compartment.

Are the metals transferred from the soil to the insects that feed on *Vicia faba L*. plants that have grown on a biochar-enriched or unenriched mine soil?

To feed, the aphid inserts its rostrum into the plant and suck up the sap containing metal(loid)s





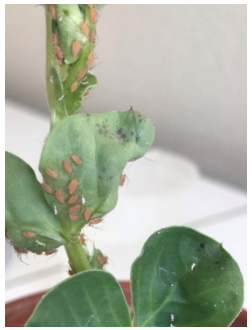


	Pb (mg/kg DW)	Cu (mg/kg DW)	Zn (mg/kg DW)
Touissit soil	8664 +/- 552	1882 +/- 137	4755 +/- 68

	Bn
pH	8.37 ± 0.02[a]
EC (µS·cm⁻¹)	257.2 ± 2.18[b]

+ 5% biochar HW

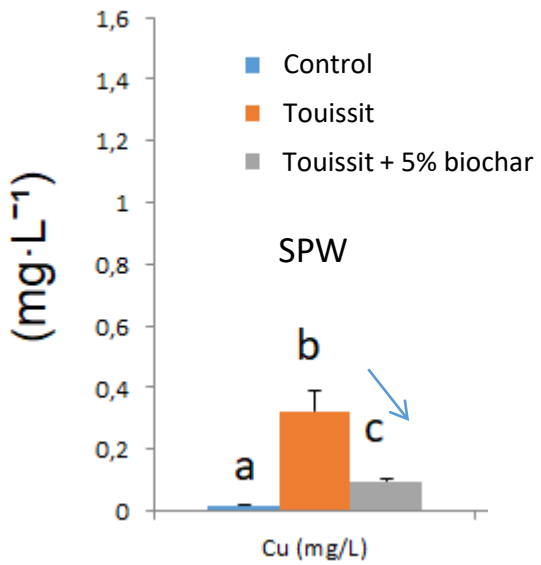
+10 female aphids

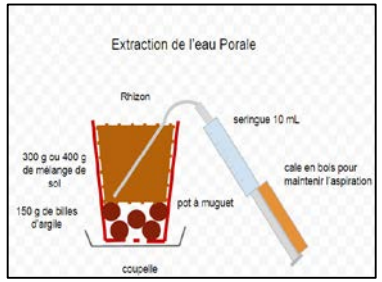


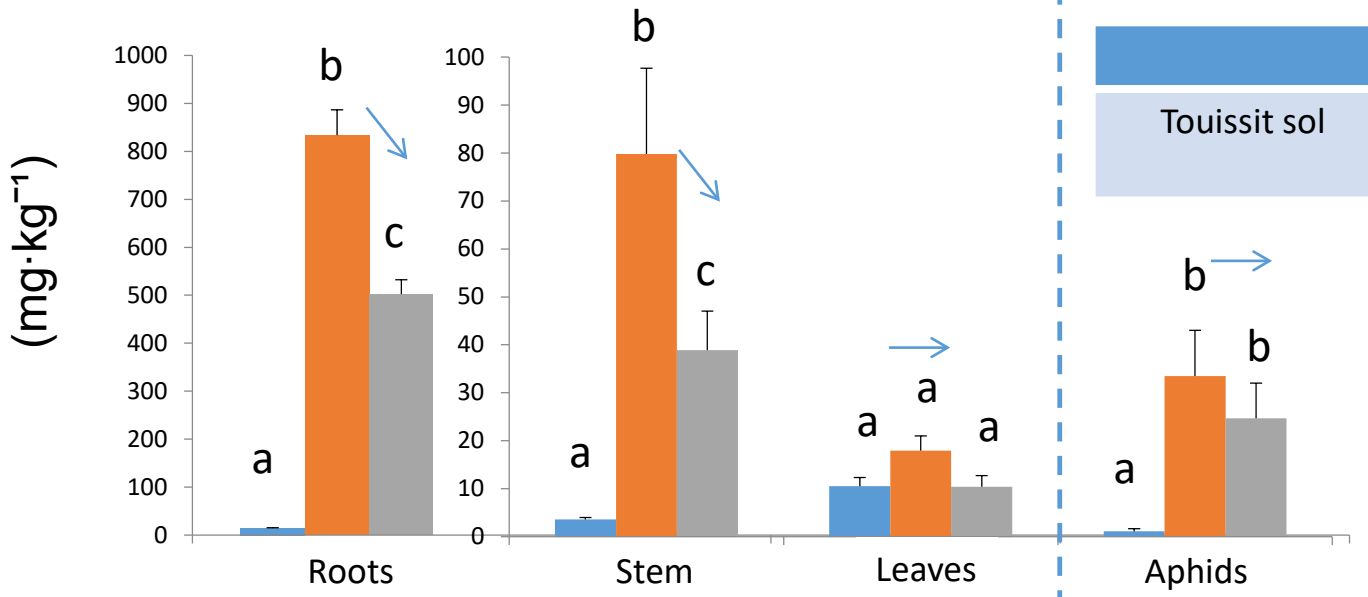
On each plant, 10 adult aphids laid young females for 3 days by means of parthenogenesis, then the adults are removed and the young females proceed to develop by feeding on the plants

29 Cu Copper 63.546

Copper concentration in the different organs of faba beans and in aphids





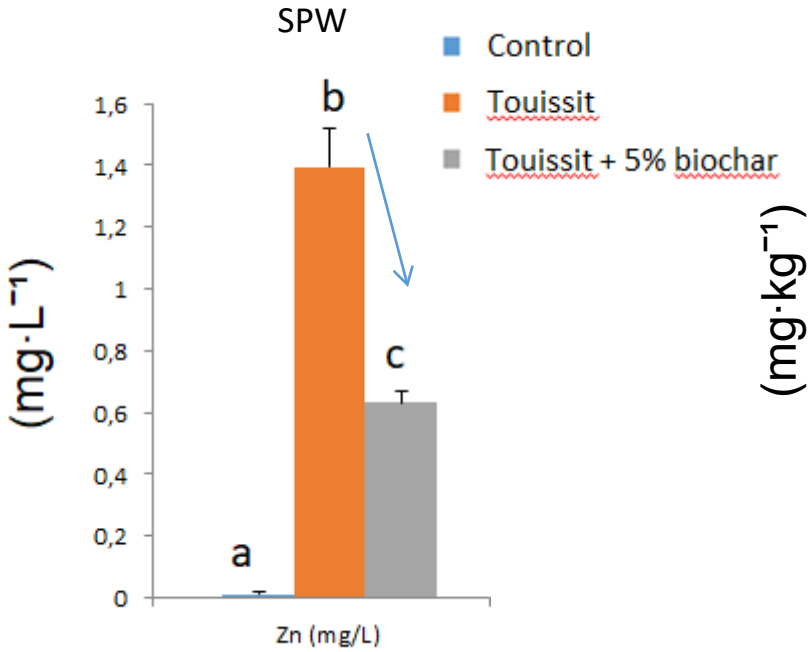


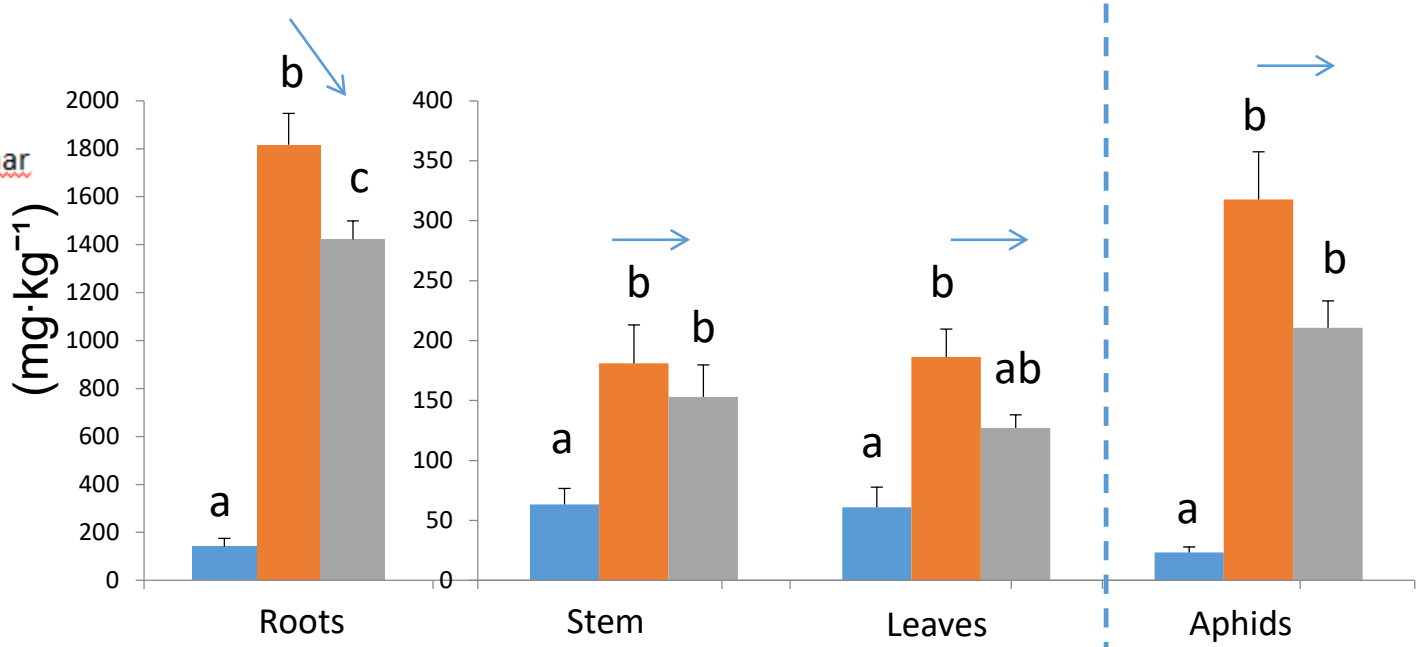
	Cu (mg/kg DW)
Touissit sol	1882 +/- 137

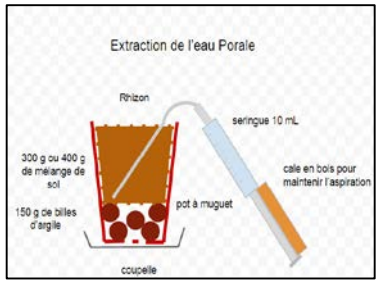
30 Zn Zinc 65.38

Zinc concentration in the different organs of faba beans and in aphids

	Zn (mg/kg DW)
Touissit sol	4755 +/- 68



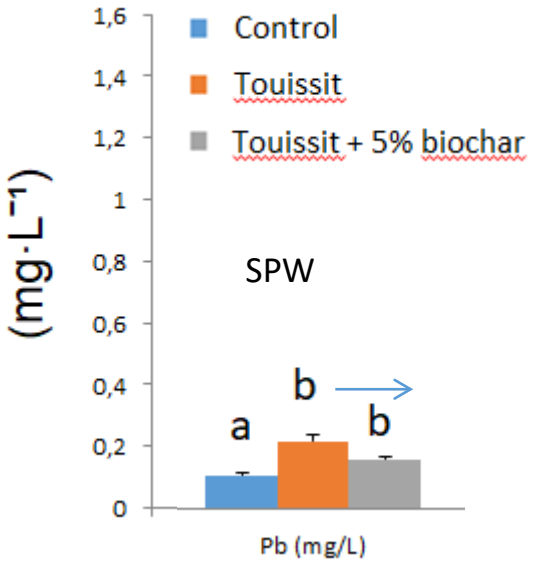


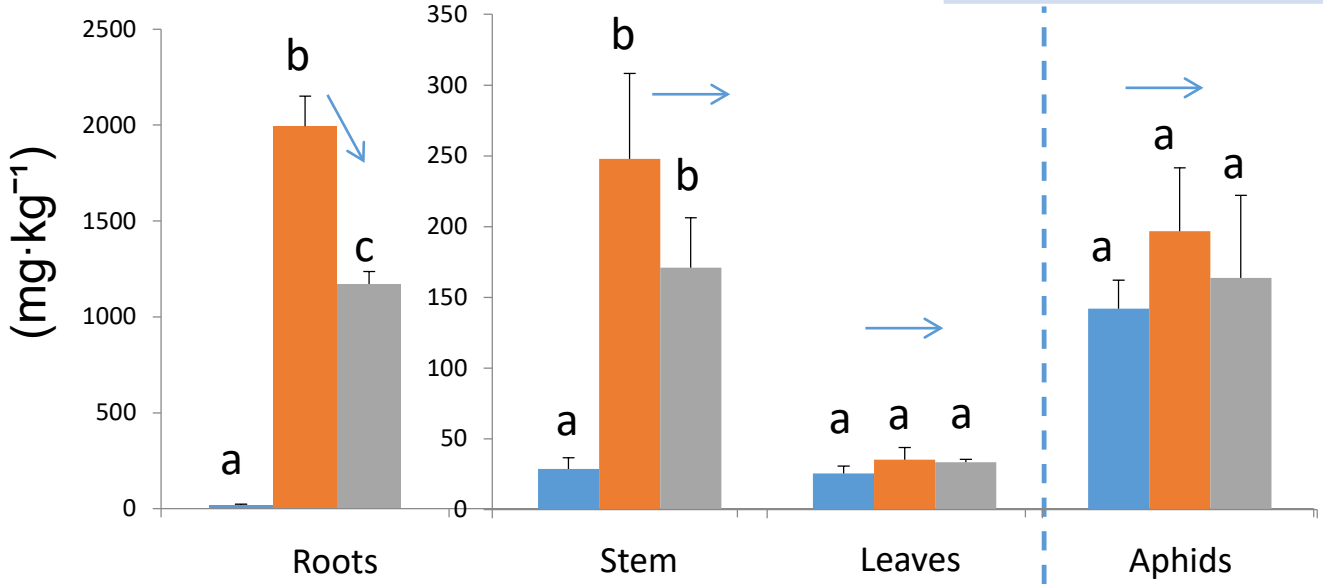


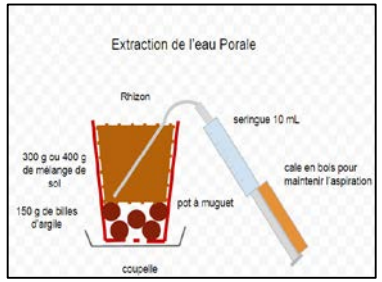
82 Pb Lead 207.2

Lead concentration in the different organs of faba beans and in aphids

	Pb (mg/kg DW)
Touissit soil	8664 +/- 552







Biochar induced :

*A decrease of the concentration of Cu and Zn in the soil pore water, no difference for Pb.
*A decrease of the concentration of Cu, Zn and Pb in roots
*No decrease of Cu, Zn and Pb in leaves
*Only a decrease of Cu in Stem

*there was no difference in Cu, Zn and Pb concentrations between aphids growing on plants placed on soil amended or not with biochar

*In all cases the concentration is lower in the plants and in the aphids compared to the soil, it is now necessary to move to the higher trophic level which corresponds to the ladybirds .

Thank you

UNIVERSITÀ DEGLI STUDI DEL MOLISE

UNIVERSITE D'ORLEANS | COLLEGIUM Sciences & Techniques Orléans - Bourges - Chartres

La Carbonerie — L'innovation dans la Chimie du Végétal

jacobi CARBONS

D. Trupiano

E. De Zio

ARCHE — Arbres et Réponses aux Contraintes Hydrique et Environnementales

C. Hano

alteo environnement GARDANNE — alumine & environnement

G. S. Scippa

LBLGC — Laboratoire de Biologie des Ligneux et des Grandes Cultures — UPRES EA 1207

GHENT UNIVERSITY

Ecochem UGent

G. Naclerio

A. Bucci

E. Destandeau

L. Fougère

icoa

R. Van Poucke

F. Tack