Phytomanagement as Solutions to reclaim degraded Areas and to enhance the Quality of urban Environment

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Co-funded by the Erasmus+ Programme of the European Union

Degradation and contamination of urban ecosystems

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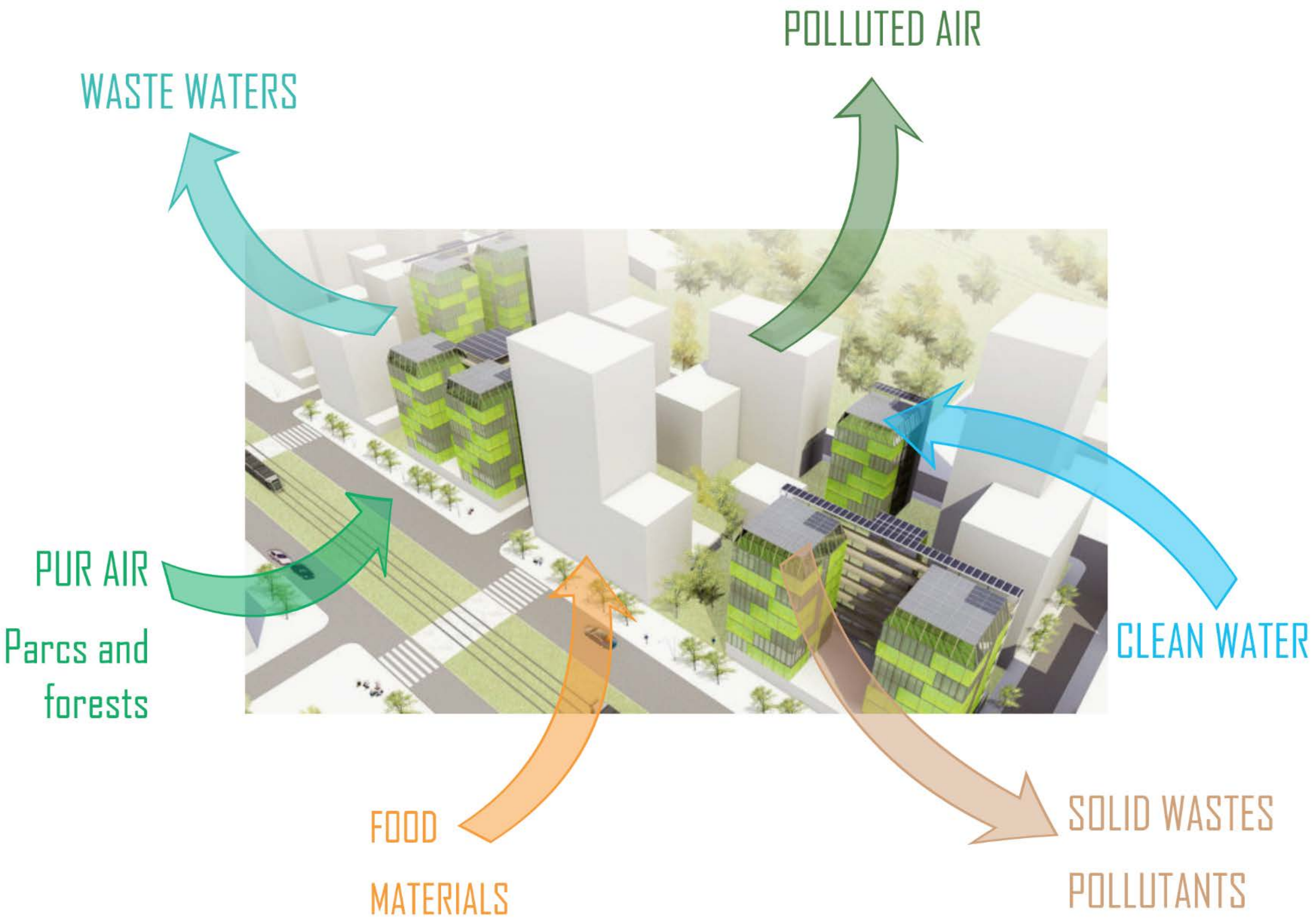
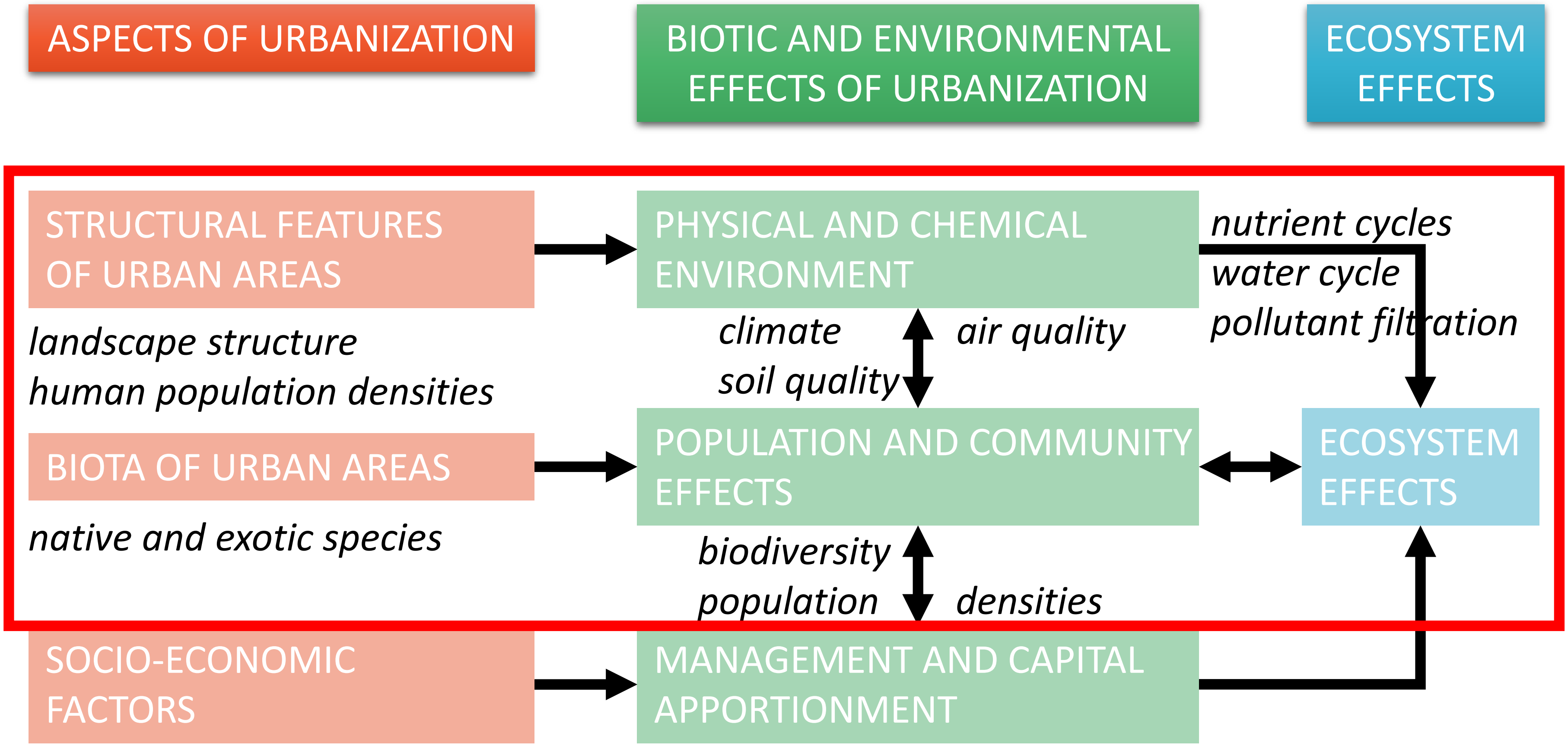
Fluxes in urban Ecosystem



Effect of urbanization on ecological phenomena



McDonnell et al 2008 Urban Ecosystems

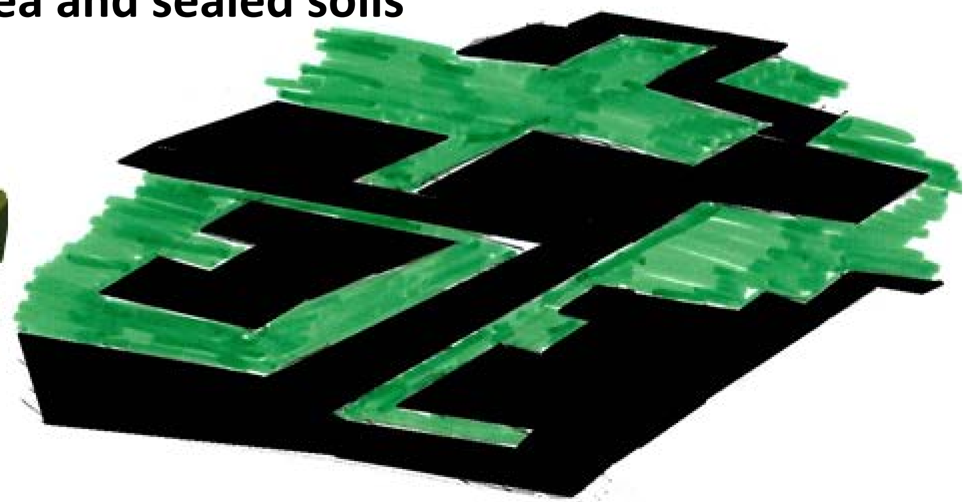
Effect of urbanization on stream ecosystems

- https://www.youtube.com/watch?v=BYwZiiORYG8

Effect of urbanization on soils

- Soil sealing
  - destruction or covering of soils by buildings, constructions and layers of completely or partly impermeable artificial material (asphalt, concrete, etc.)
  - most intense form of land take and is essentially an irreversible process

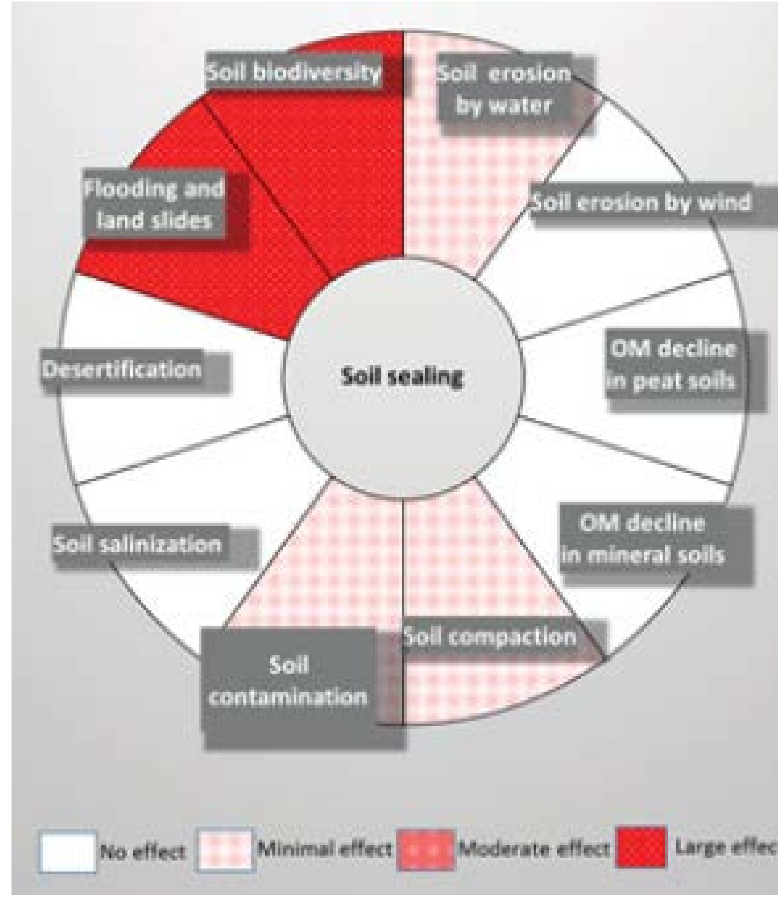
Settlement area and sealed soils



Recare project (https://www.recare-hub.eu/soil-threats/sealing)

Effect of urbanization on soils

Interaction with other threats



- Soil sealing

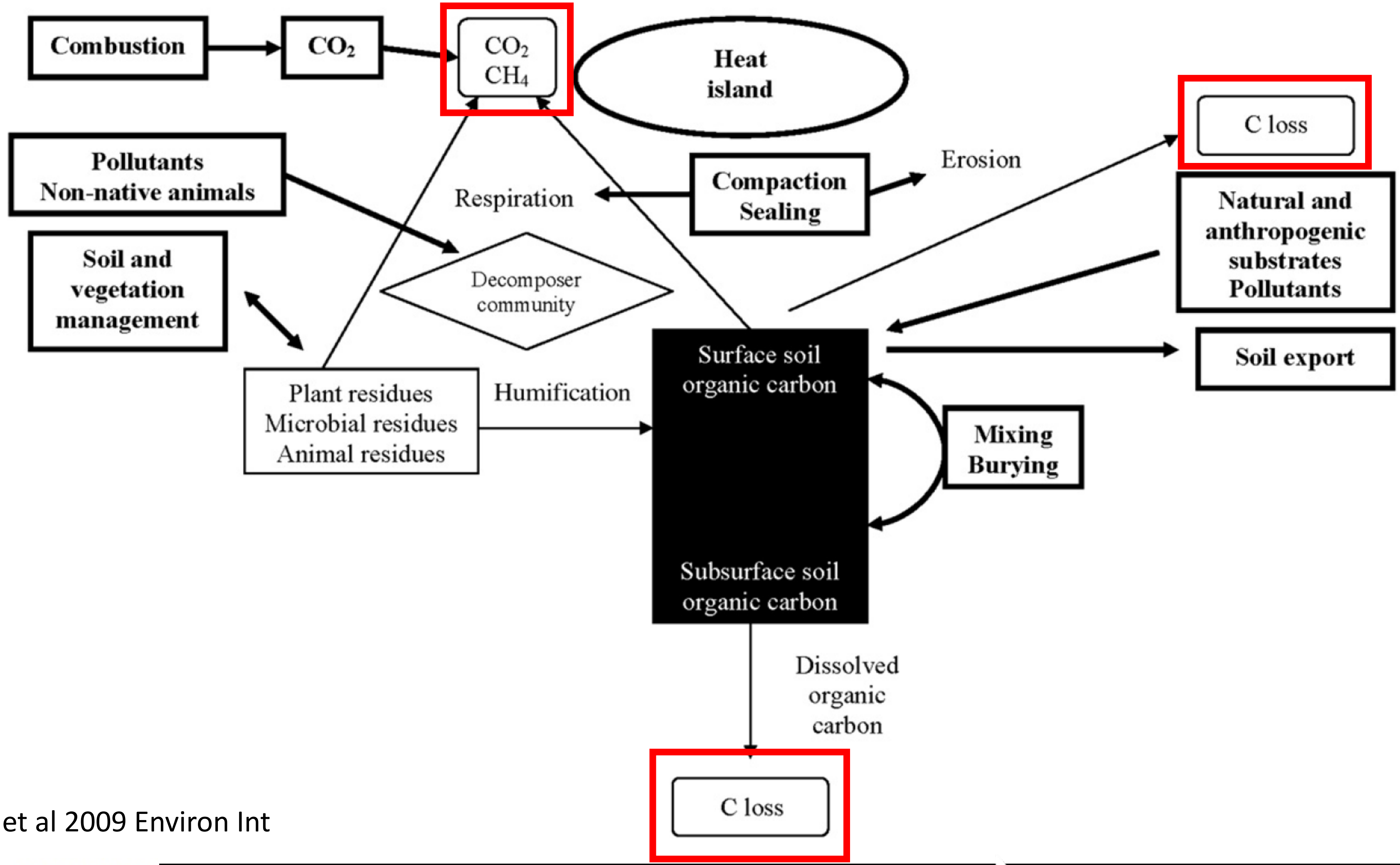
Alteration of soil functions

Biomass production	Storing/filtering/ transforming	Gene pool (diversity)	Physical basis	Raw materials	Cultural heritage

Recare project (https://www.recare-hub.eu/soil-threats/sealing)

Effect of urbanization on soils

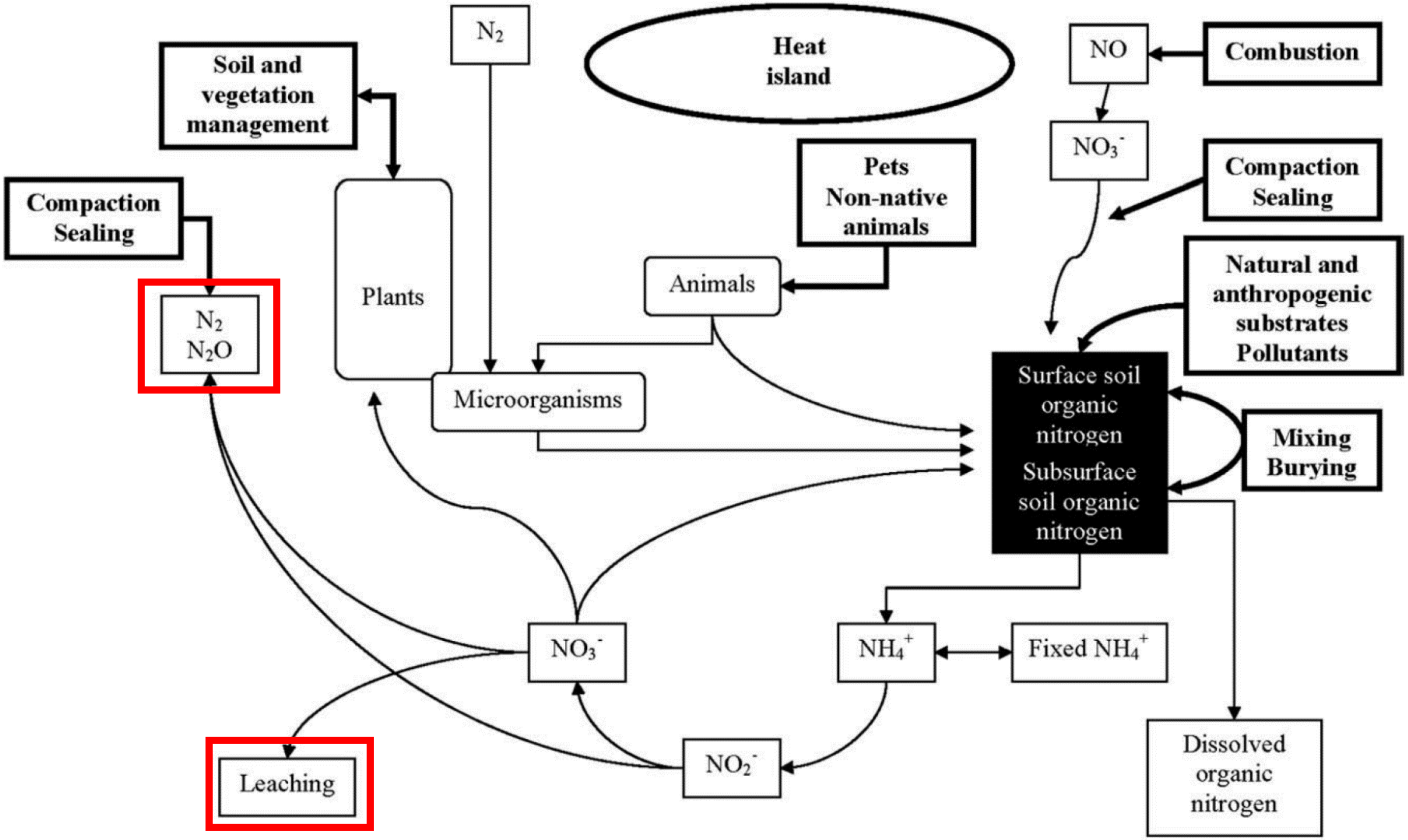
- Modifications of the biogeochemical C and N cycles



Lorenz et al 2009 Environ Int

Effect of urbanization on soils

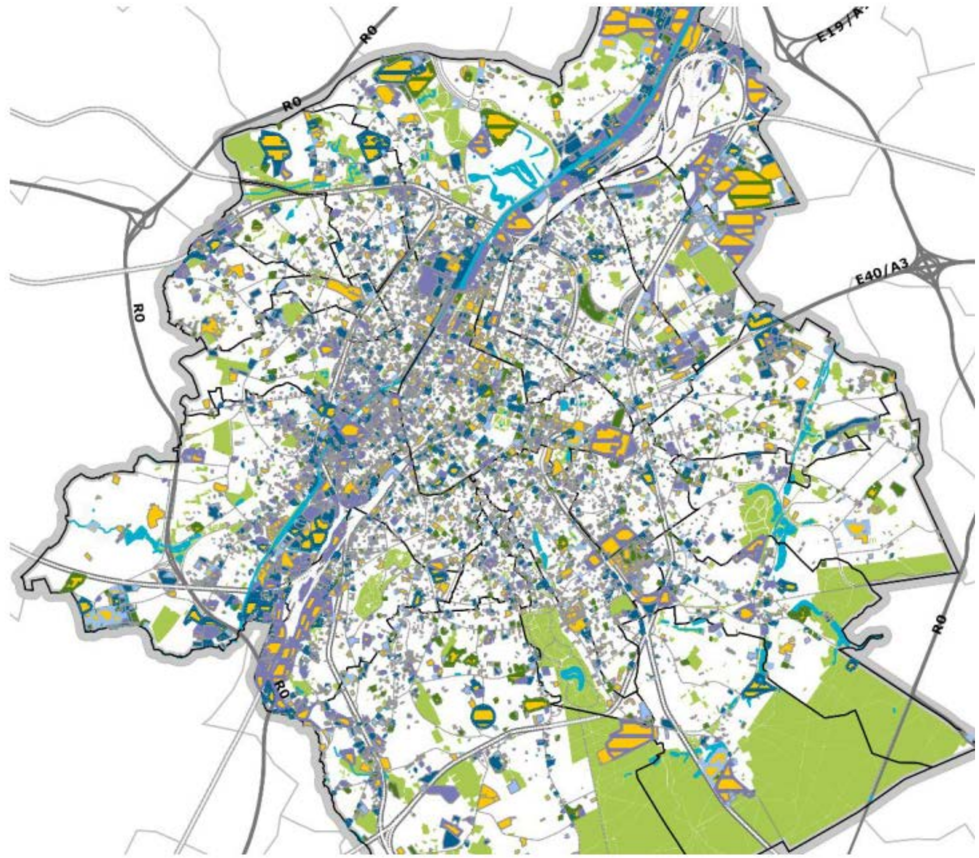
- Modifications of the biogeochemical C and N cycles



Lorenz et al 2009 Environ Int

Effect of urbanization on soils

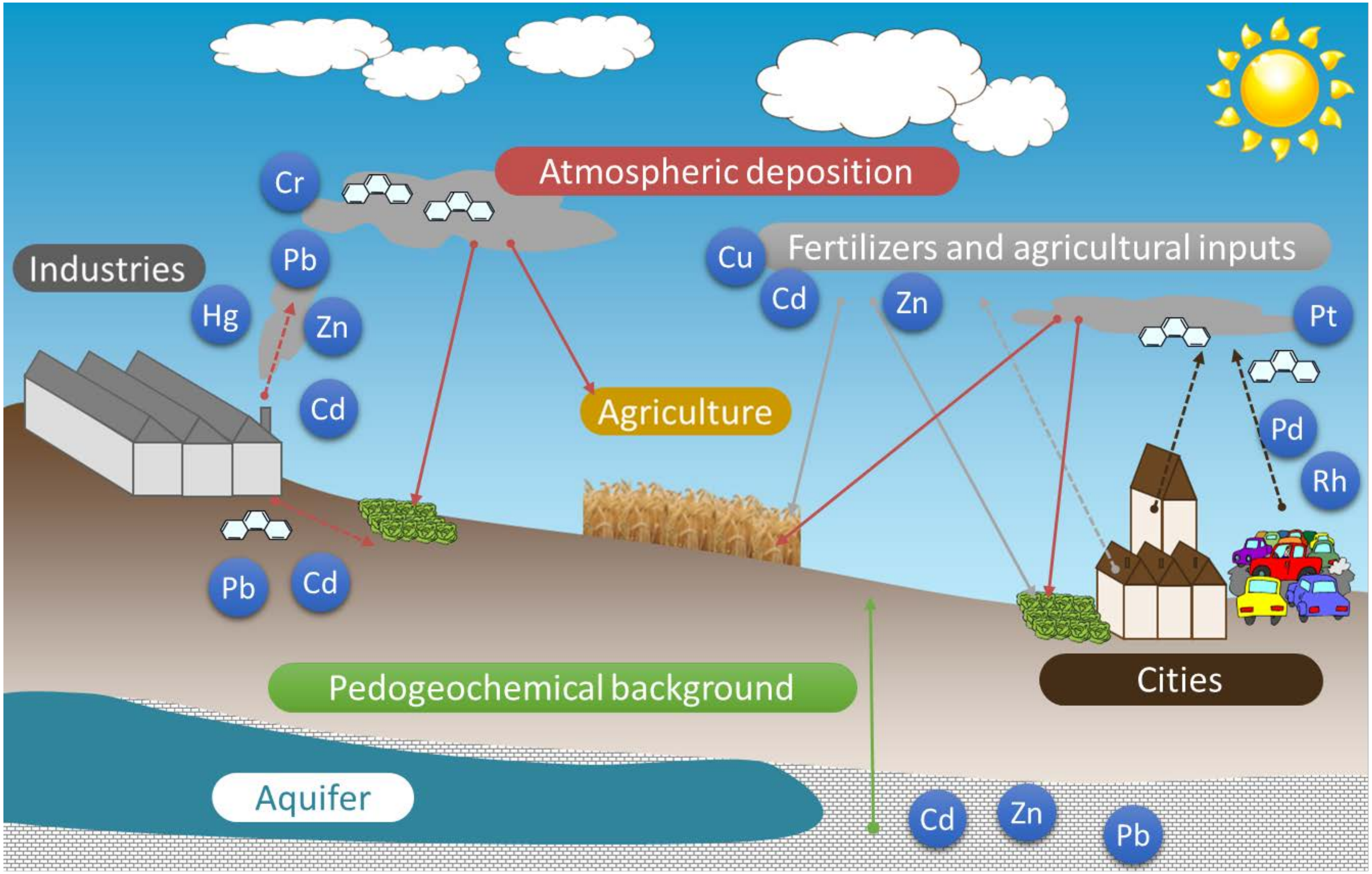
- Soil pollution: case study of Bruxelles
  - 18% of the total surface potentially contaminated
  - main pollutants: mineral oils (40%), trace elements (25%) and PAH (25%)
  - 479 ha remediated
  - total cost 403 M€ (84 € m^{-2})



Bruxelles Environnement, sous-division Sols, 2015

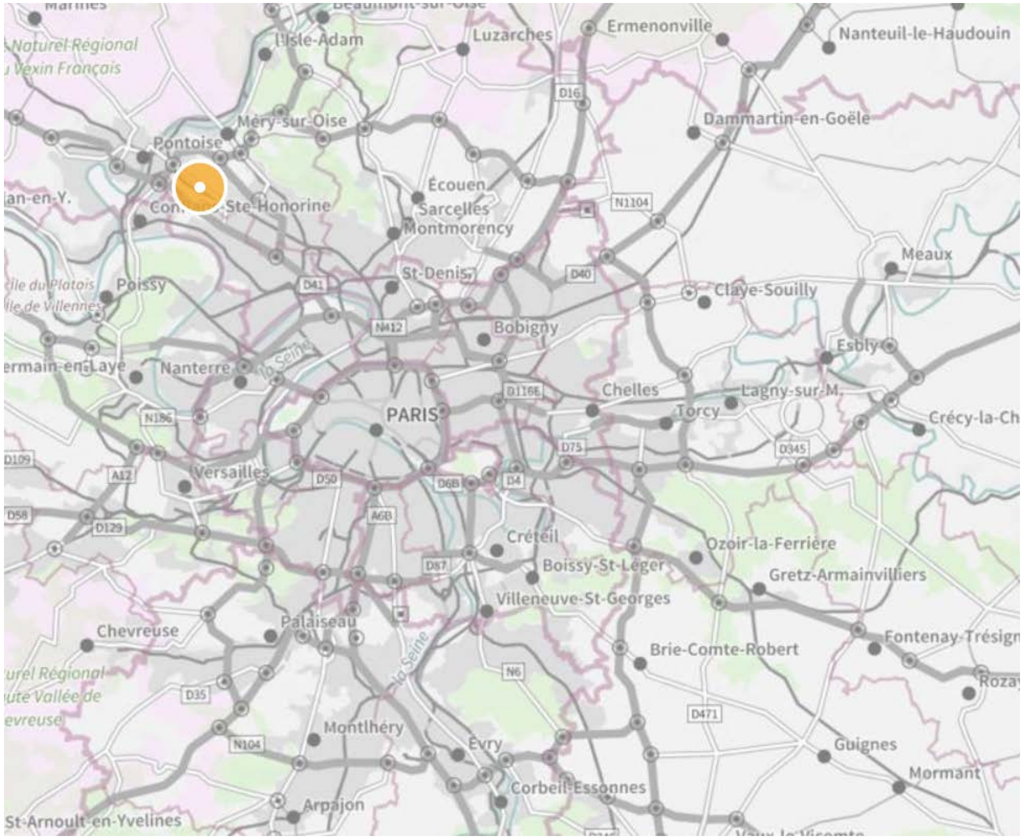
Effect of urbanization on soils

- Soil pollution: main pathways for pollutants entering the soil



Effect of urbanization on soils

- Fertilizers as sources of contaminants in urban soils: case study of Pierrelaye, France
  - suburban area of Paris



Lamy et al 2004 Rapport final EPANDAGRI

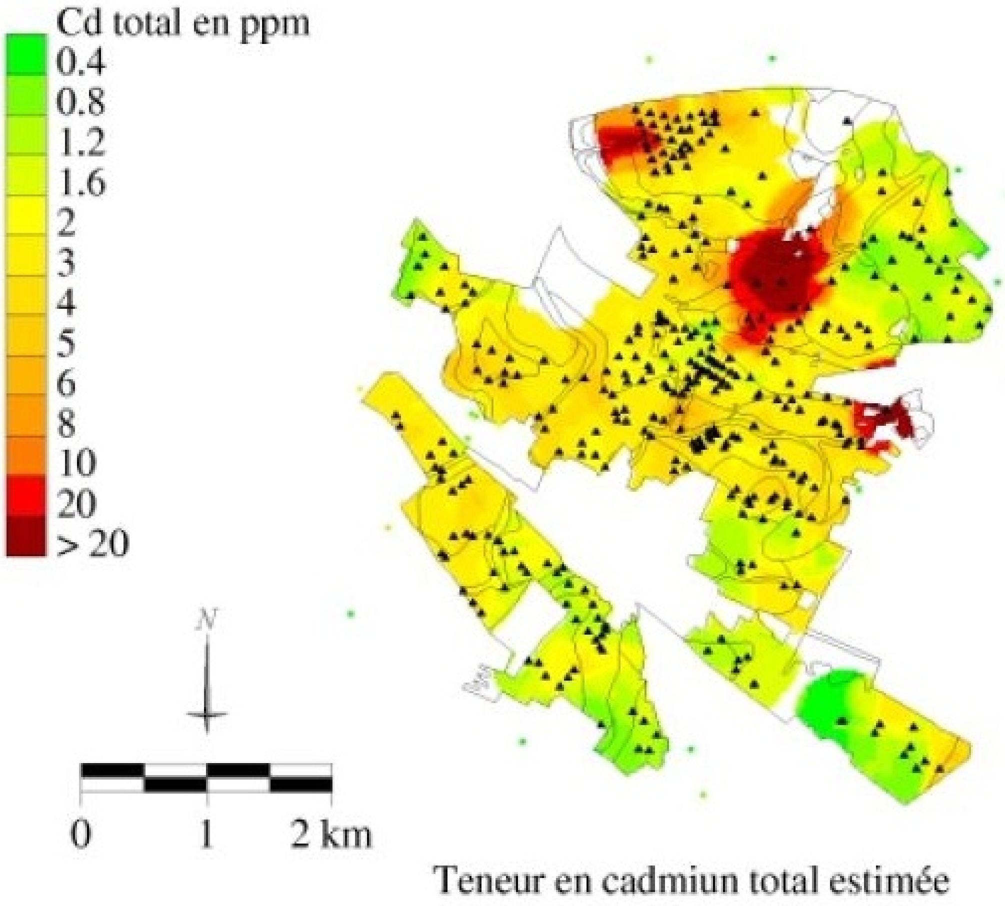
Effect of urbanization on soils

- Fertilizers as sources of contaminants in urban soils: case study of Pierrelaye, France
  - suburban area of Paris
  - raw wastewater spreading for more than 100 years
  - 1200 ha of sandy soil used for market gardening

Lamy et al 2004 Rapport final EPANDAGRI

Effect of urbanization on soils

- Fertilizers as sources of contaminants in urban soils: case study of Pierrelaye, France
  - suburban area of Paris
  - raw wastewater spreading for more than 100 years
  - 1200 ha of sandy soil used for market gardening
  - entering of significant amounts of pollutants
  - ban on market gardening
  - search for solutions



Lamy et al 2004 Rapport final EPANDAGRI

Organisms as reclamation tools

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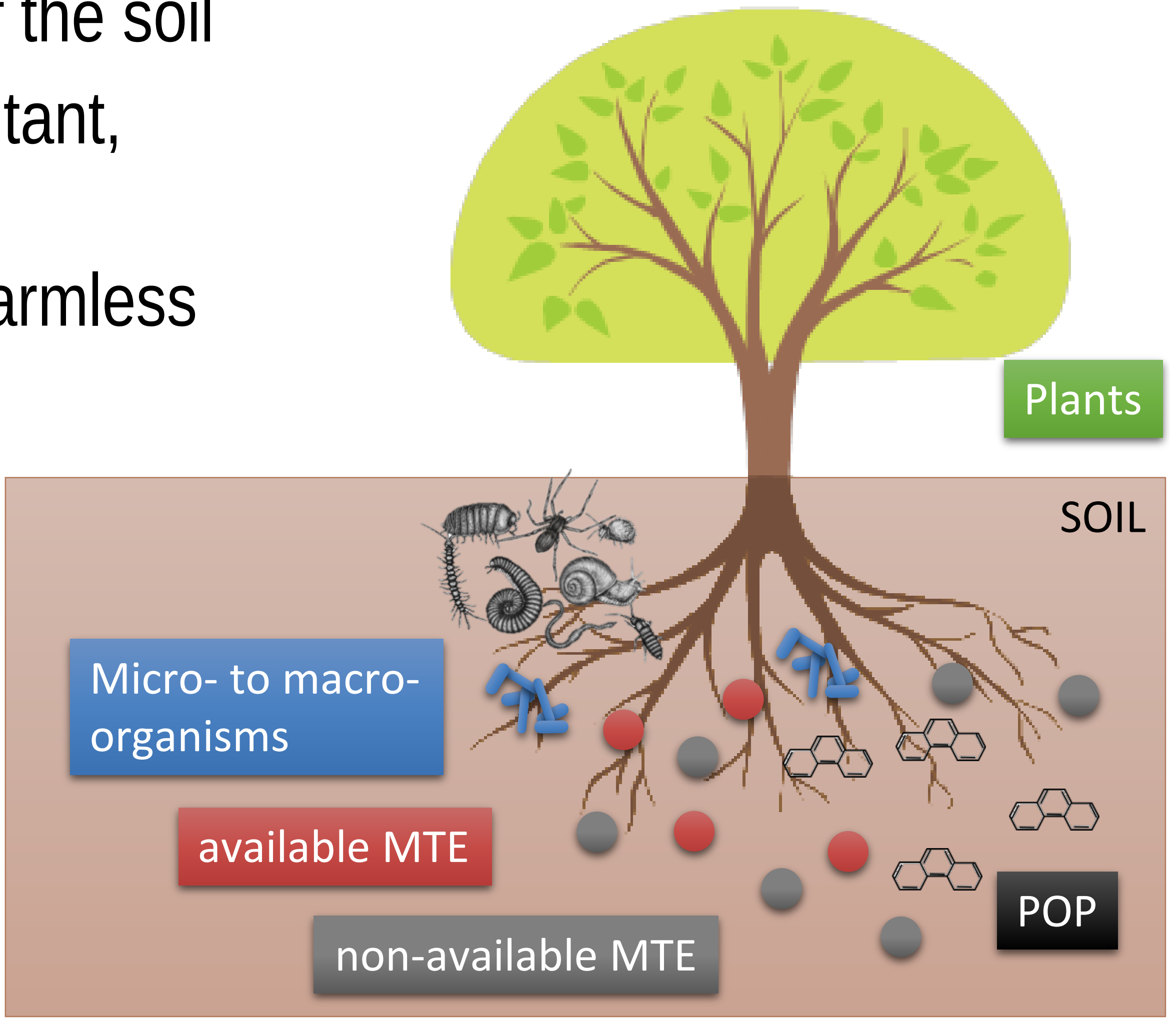
Actors and objectives

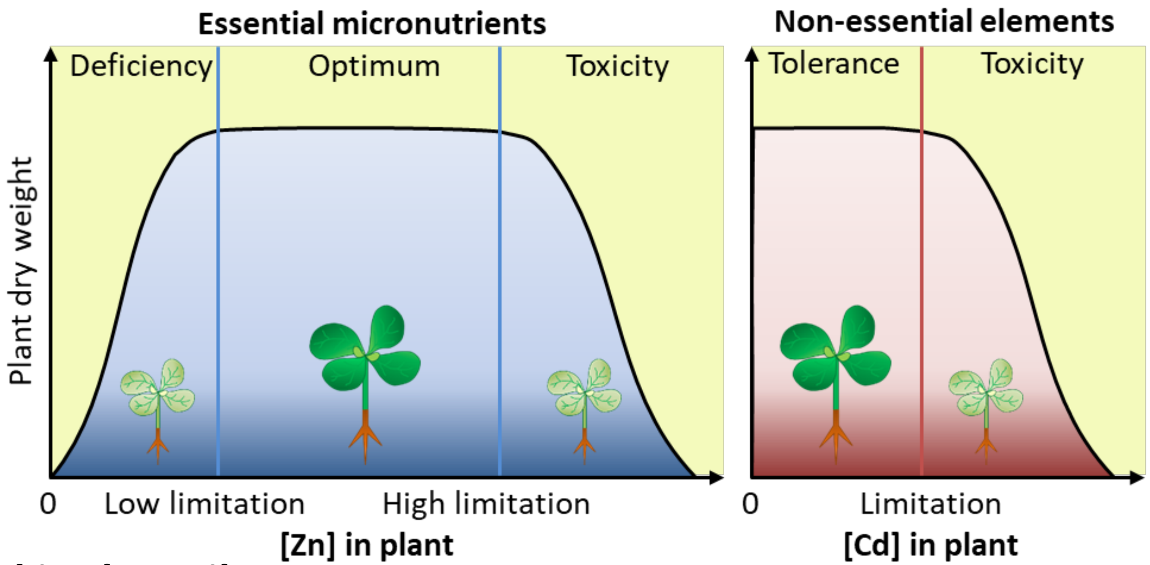
- Reduce the risks associated with a planned use of the soil
- Eliminate all the pollutant, if possible
- Otherwise, make it harmless



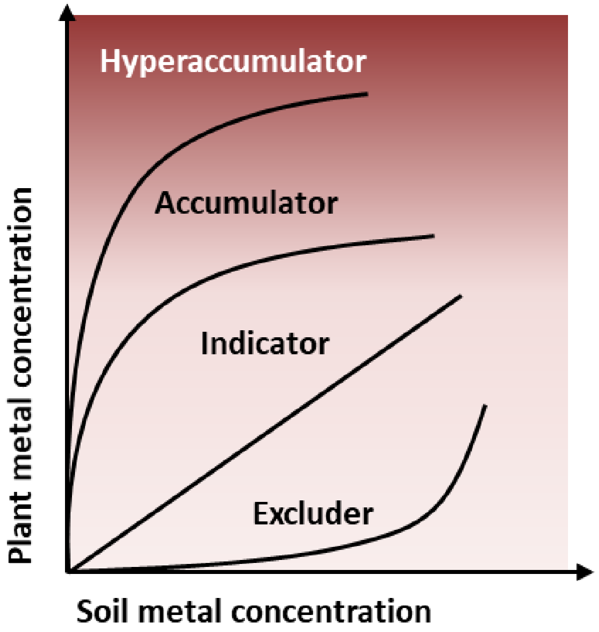
Actors and objectives

- Plant response in the presence of trace elements…

in the plant…



The absorption of metals depends on the bioavailability of pollutants



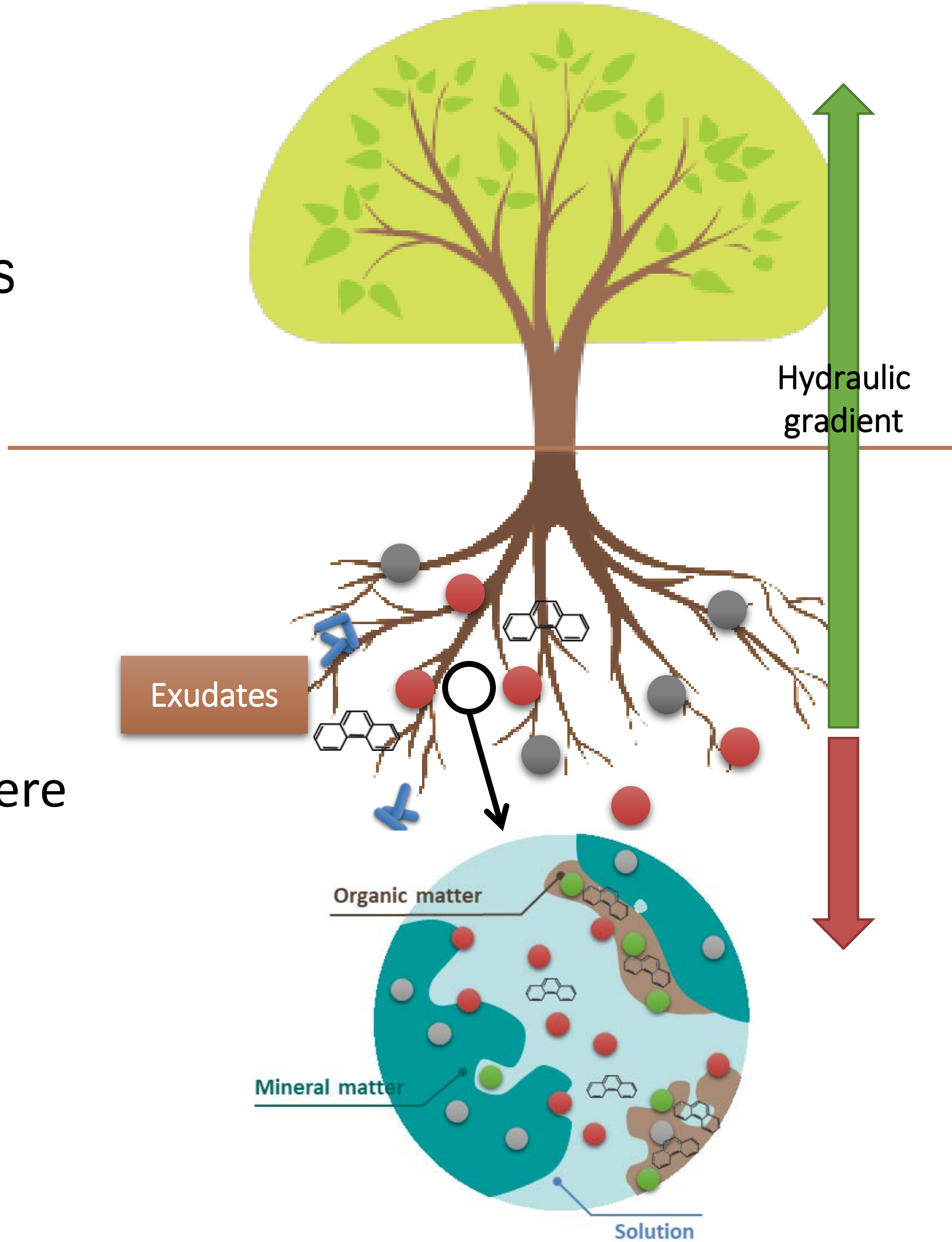
and in the soil

- Depends on plant species and degree of soil cover by plants
- Depends on the degree of soil pollution by trace elements

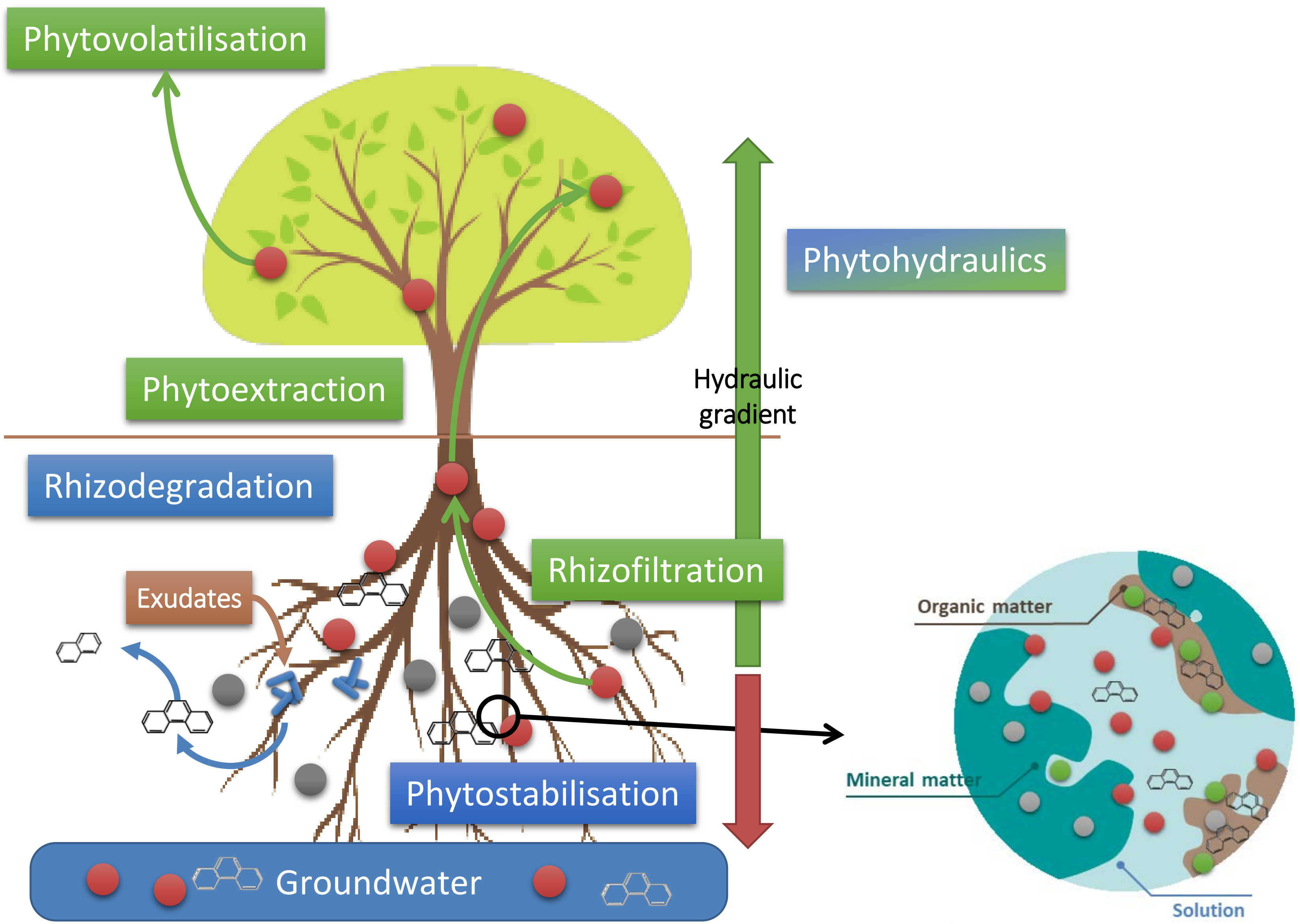
Baker 1981, Lin and Aarts, 2013

Means of action

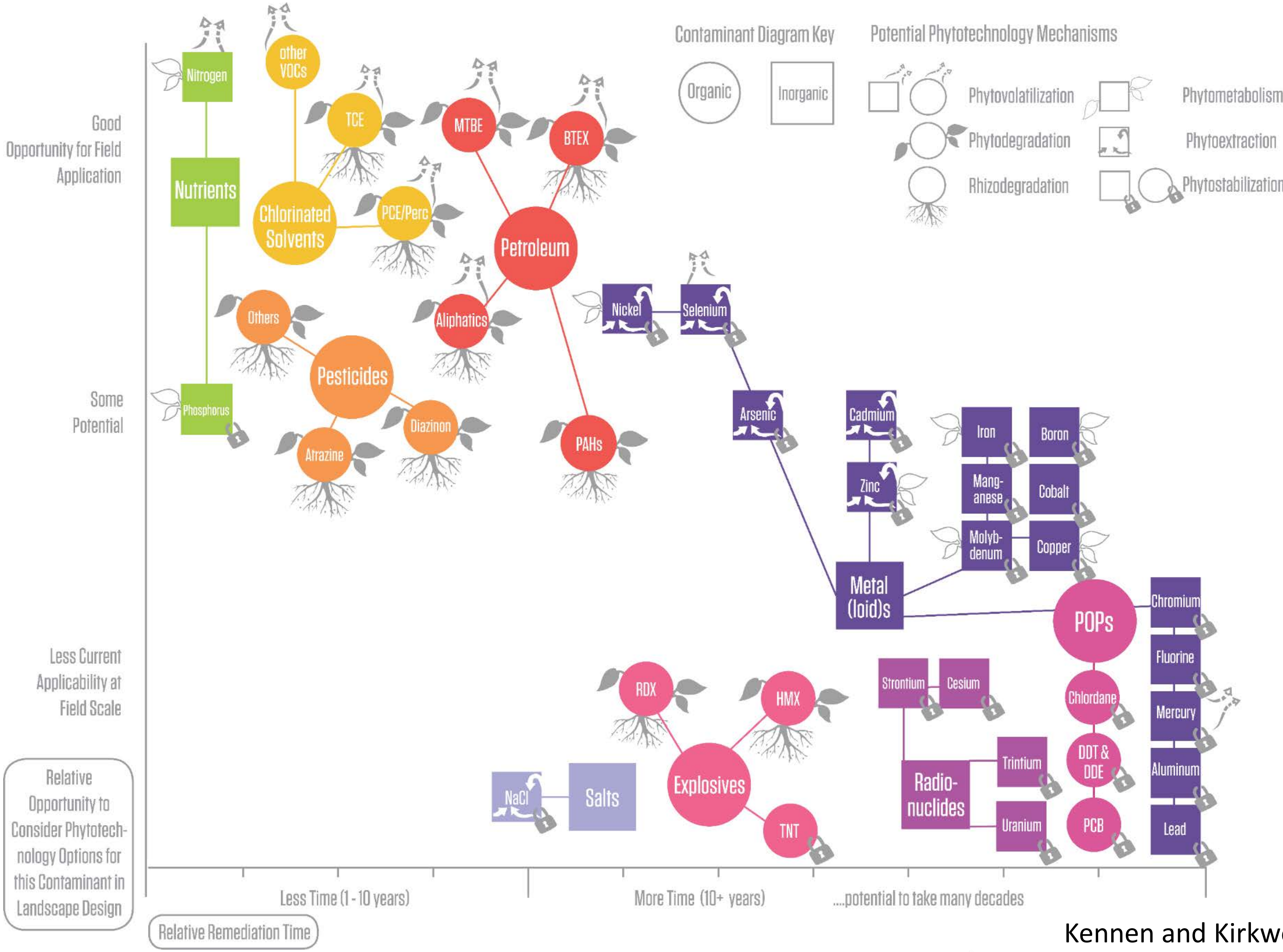
- Plant and organisms species
- Modifications of pollutants properties
  - physical and chemical modification of soils
    - aeration (O_2, porosity)
    - potential as pollutant sink
    - pollutant availability
  - transformation of pollutants
  - release of exudates by plants and increase of Corg in rhizosphere
  - interception and delay of pollutants movements
- Optimization of growing conditions
  - physical and chemical fertility



Phytotechnologies

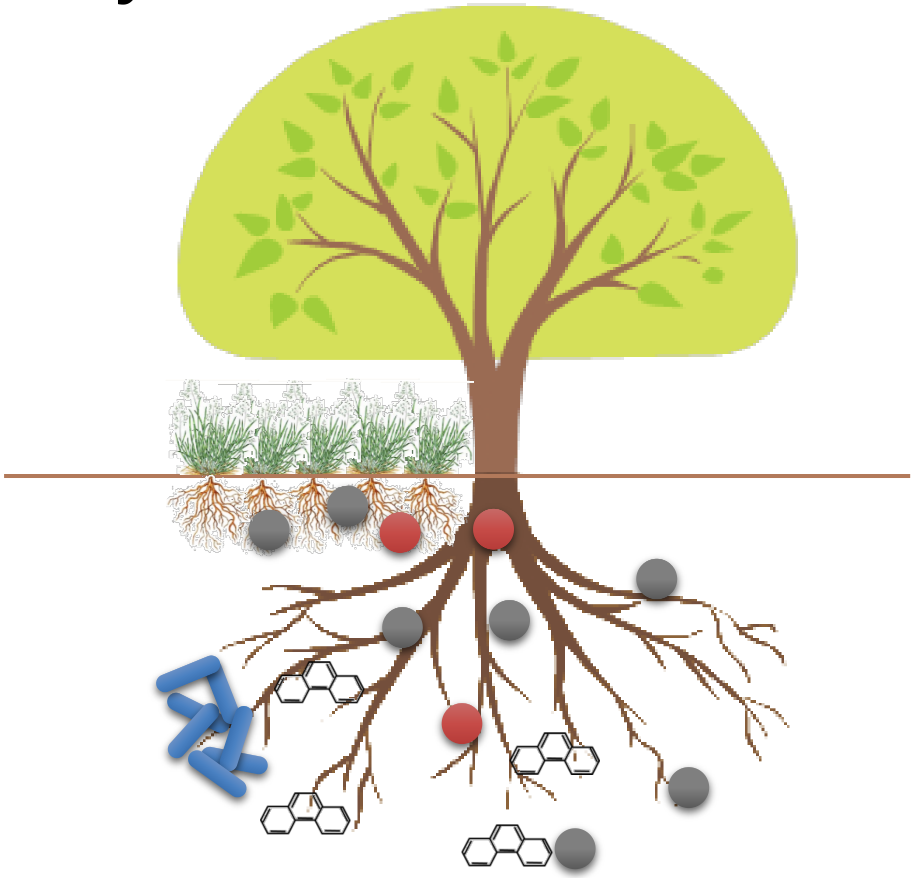


Phytotechnologies



Kennen and Kirkwood 2015

Phytostabilization

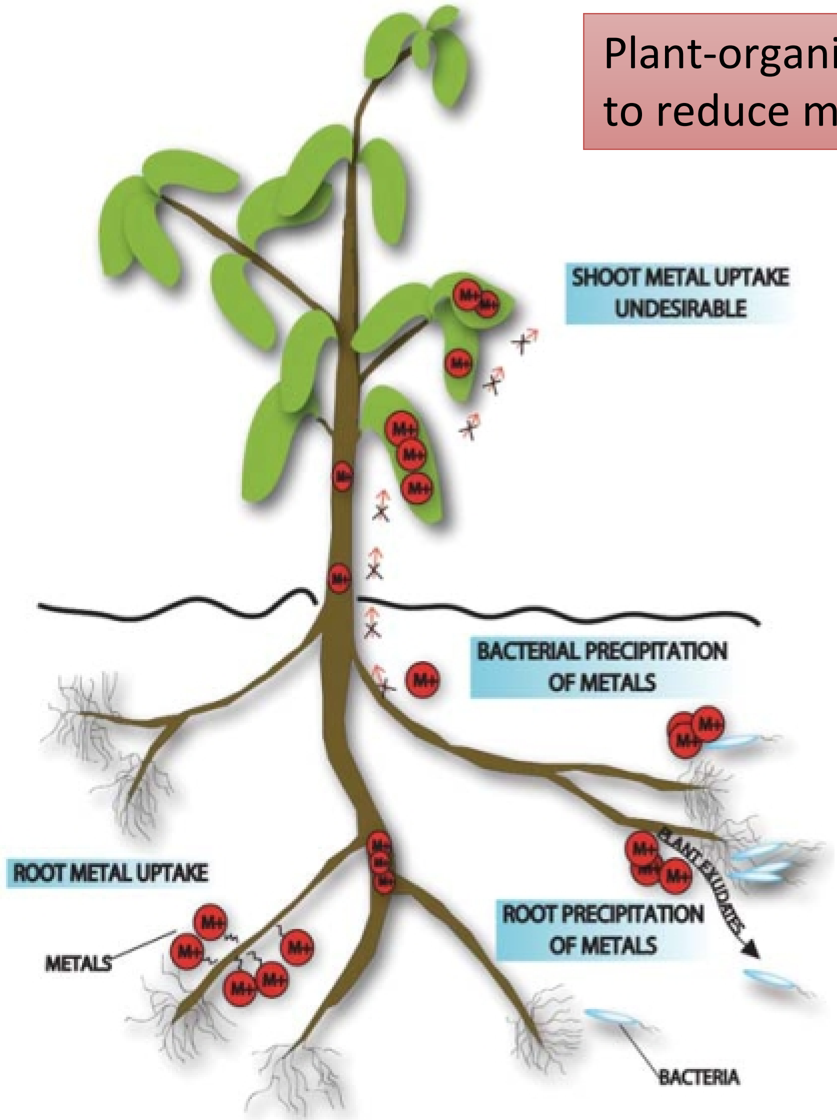


- Use tolerant plants and amendments to immobilize soil pollutants
  - Reduced risk of air-borne contaminated particles
  - Reduced risk of leaching of metals to groundwater through evapotranspiration
  - Formation of a barrier between humans or animals and contaminated soil

2 mecanisms: chemical and biological

Phytostabilization

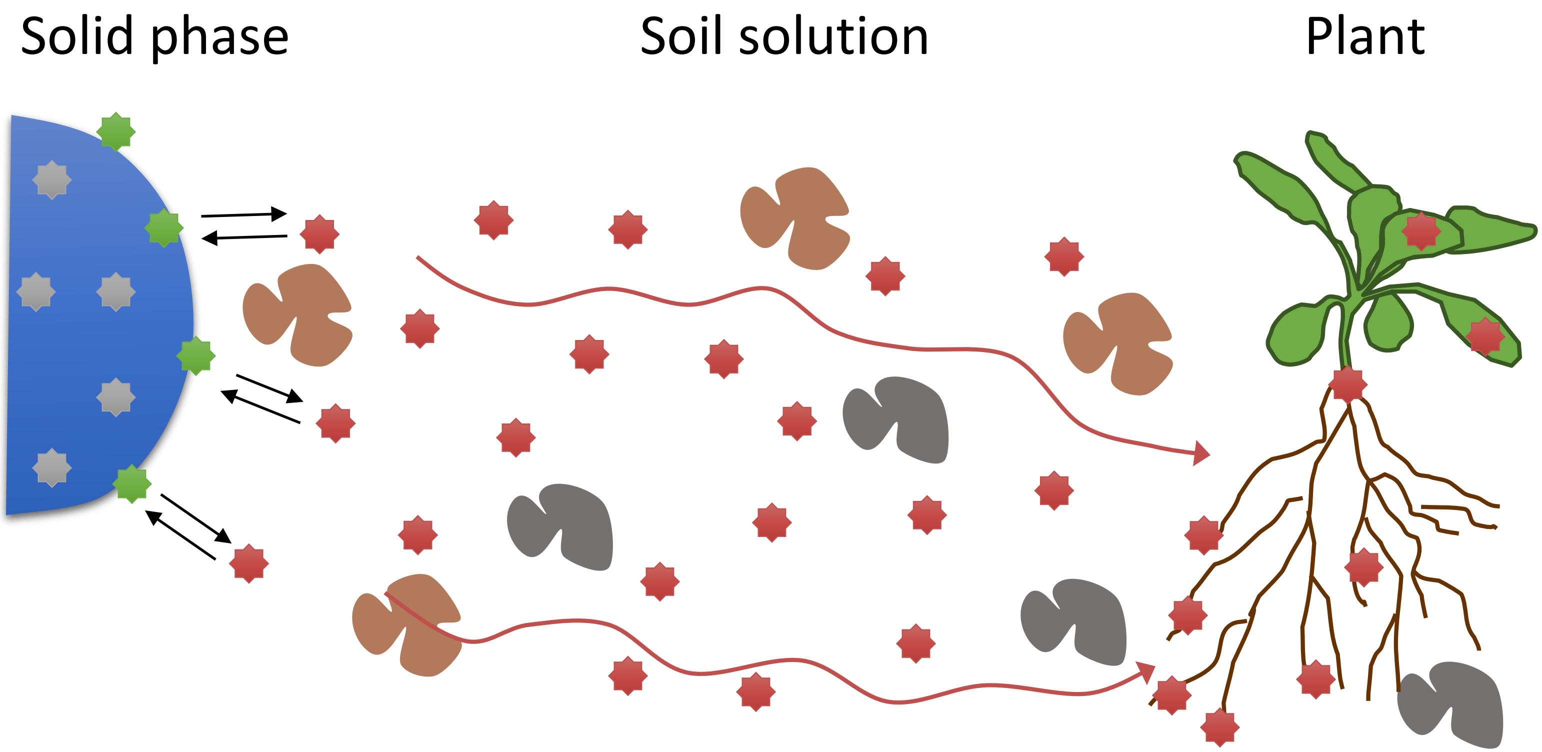
Plant-organisms association to reduce metal availability

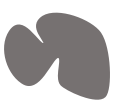


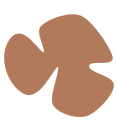
Mendez and Maier 2008 Environ Health Perspect

Phytostabilization

Reduction of the availability of metals through a pH effect (carbonates), the fixation on solid phases (↗ CEC) or the decrease of oxydo-reduction variation (upward hydraulic gradient)

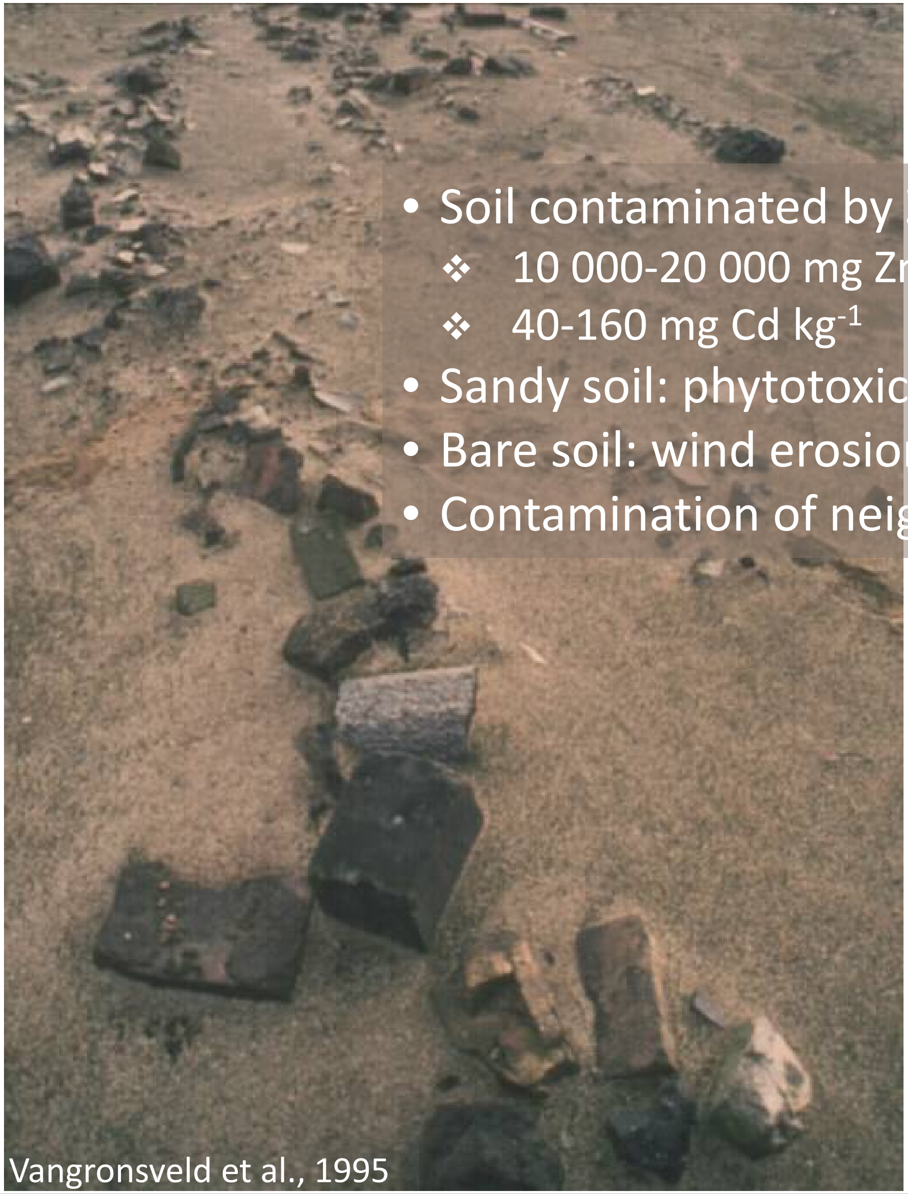


 Inorganic amendments (phosphate minerals, liming materials, pure or combined aluminium silicate, Fe, Al and Mn oxydes or hydroxydes…)

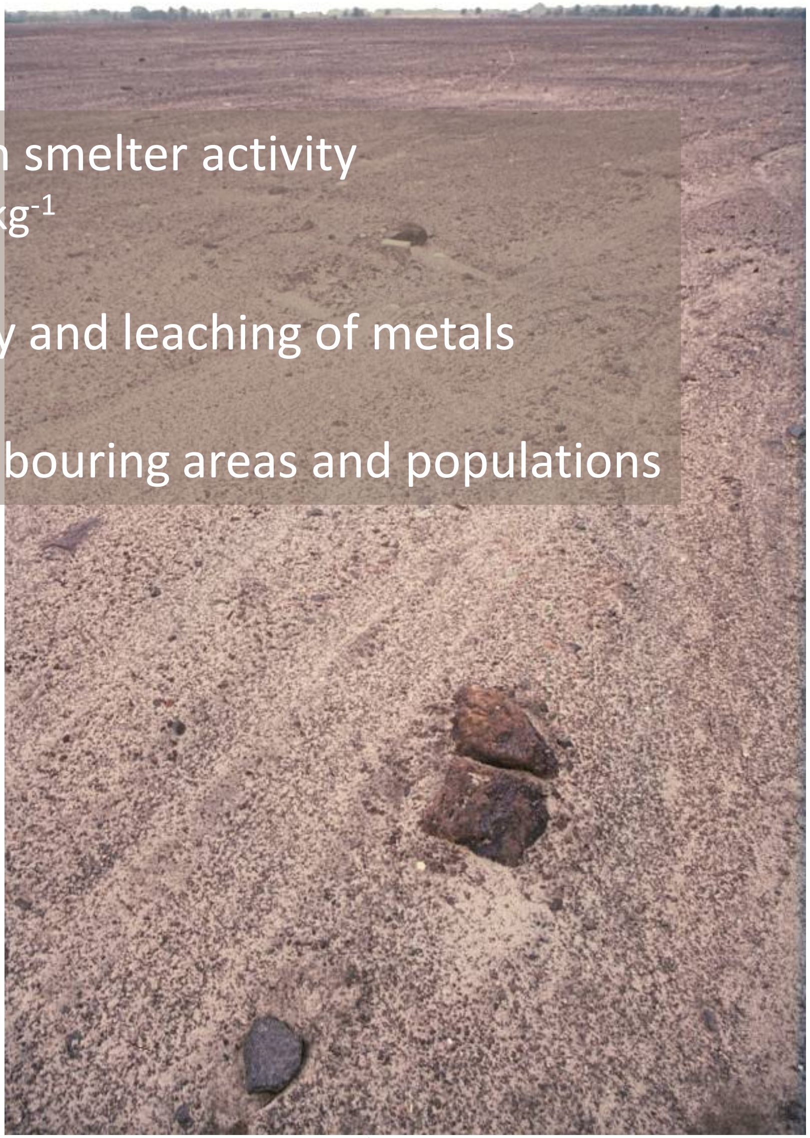
 Organic amendments (compost, biochar, straw…)

Phytostabilization

- Soil contaminated by Zn smelter activity
  - ❖ 10 000-20 000 mg Zn kg^{-1}
  - ❖ 40-160 mg Cd kg^{-1}
- Sandy soil: phytotoxicity and leaching of metals
- Bare soil: wind erosion
- Contamination of neighbouring areas and populations



Vangronsveld et al., 1995



Phytostabilization

Soil preparation and amendments supply

Vangronsveld et al., 1995

Phytostabilization

1995: installation of a vegetal cover

Vangronsveld et al., 1995

Phytostabilization

2002: succesfull plant cover

Vangronsveld et al., 1995

Phytostabilization

- Natural attenuation
  - iron and steel manufacturing complex from 1872 to 1986
    - iron ore processing
    - settling pond of 2.6 ha and ca. 10 m deep deposit
    - successive sludge supplies until ca. 1950
    - pond colonization by plants

Phytostabilization

- Natural attenuation
  - development of a decideous forest

Looks like a natural forest !

Huot et al., 2013

Phytostabilization

- Some representative metal exluders

Bentgrass (*Agrostis tenuis*)

Rygrass (*Lolium sp*)

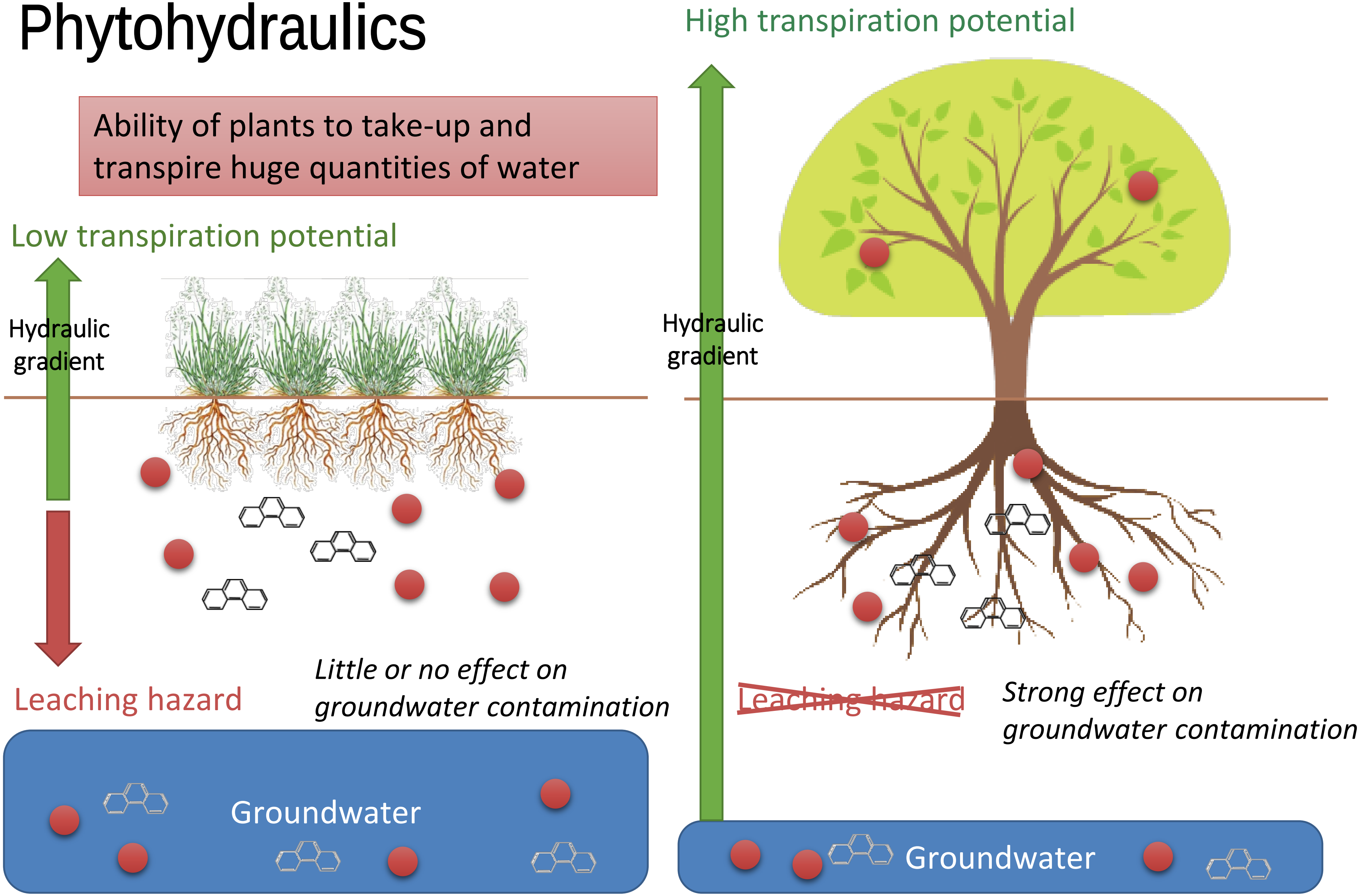
Red fescue (*Festuca rubra*)

Gorse (*Ulex europeus*)

Holm oak (*Quercus ilex*)

Phytohydraulics

Ability of plants to take-up and transpire huge quantities of water



Phytohydraulics

- Some phreatotype plant species

Elderberry (*Sambucus* sp)

Alder (*Alnus* sp)

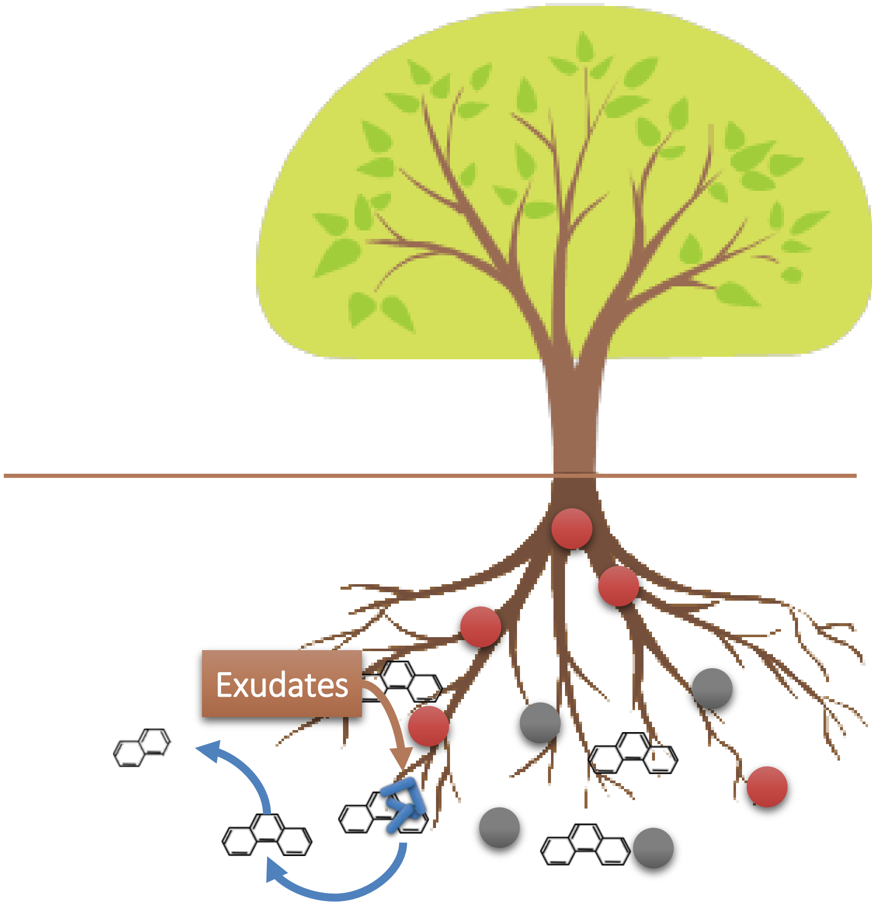
Poplar (*Populus* sp)

Eucalyptus (*Eucalyptus* sp)

Willow (*Salix* sp)

Rhizodegradation

- Use plants in cooperation with microorganisms
  - To accelerate the degradation of organic (pesticides, PAHs, PCBs) or inorganic (perchlorates) molecules
  - Valuing the rhizosphere effect
  - Remove contaminants by **rhizodegradation** or **rhizotransformation** via plant enzymes or enzymatic cofactors



Rhizodegradation

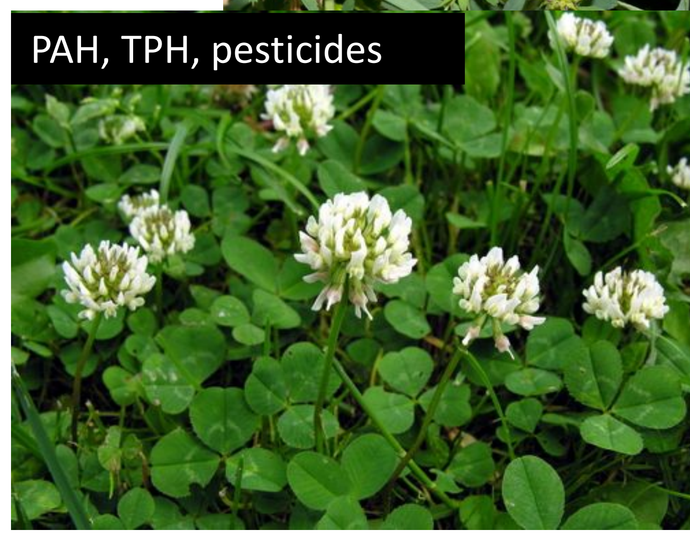
- Some organic compounds degradation plants

Poplar (*Populus* sp)

Willow (*Salix* sp)

Alfalfa (*Medicago sativa*)

Birch (*Betula pendula*)



White clover (*Trifolium repens*)

Rhizodegradation

- Some organic compounds degradation plants

Mustard (*Brassica juncea*)

Sunflower (*Helianthus anuus*)

Giant maiden grass (*Miscanthus gigantheus*)

Rygrass (*Lolium sp*)

Red fescue (*Festuca rubra*)

Cattail (*Brassica juncea*)

Common reed (*Phragmites australis*)

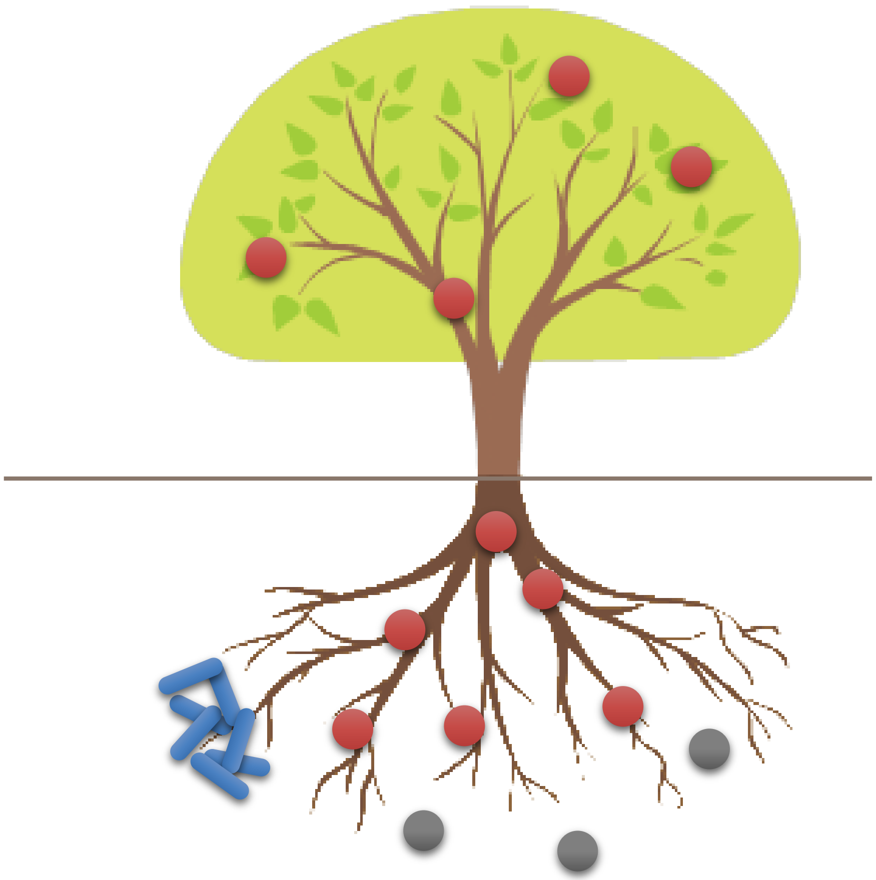
Duckweed (*Lemna minor*)

Water milfoil (*Myriophyllum aquaticum*)

Phytoextraction

- Using plants to extract soil trace elements

  - Accumulator plants with a high biomass production (*Brassica juncea, Salix*)
  - Hyperaccumulator plants (*Noccaea caerulescens, Alyssum murale*)



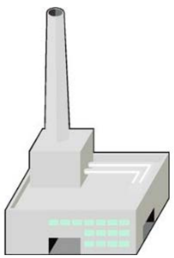
Phytoextraction

Plant cultivation

Chemical agents

Ni^{2+} Au^{+} Cu^{2+} Pd^{2+}

Plant harvest and incineration to produce bio-ore



Bio-ore smelter

Bio-ore containment

Agromining

Phytoremediation

Phytoextraction with native wild hyperaccumulators

- Ni hyperaccumulators: more than 500 species

Sebertia acuminata
New Caledonia
25% of Ni in the xylem sap

Psychotria douarei
New Caledonia
3% of Ni in plant

Beckheya coddii
South Africa
3% of Ni in plant

Alyssum murale
Greece
3% of Ni in plant

Alyssum corsica
France
1% of Ni in plant

Noccaea caerulescens
France
1% of Ni in plant

Phytoextraction with native wild hyperaccumulators

- Cd and Zn hyperaccumulators: only few species

Arabidopsis halleri
France
0,03% Cd – 1.5% Zn

Noccaea caerulescens
France
0.3% Cd – 3% Zn

Sedum alfredi
China
0.1% Cd – 1% Zn

Phytoextraction with accumulators

False oat grass (*Arrhénterum elatius*)

Mustard (*Brassica juncea*)

Sunflower (*Helianthus anuus*)

Alfalfa (*Medicago sativa*)

Poplar (*Populus* sp)

Willow (*Salix* sp)

Phytoextraction

- Metalliferous grassland on a former smelter site

Phytoextraction efficiency:
a balance between biomass production and plant metal concentration

Schwartz et al. 2001 Sci Tot Environ

Optimisation of the processes involved in phytomanagement

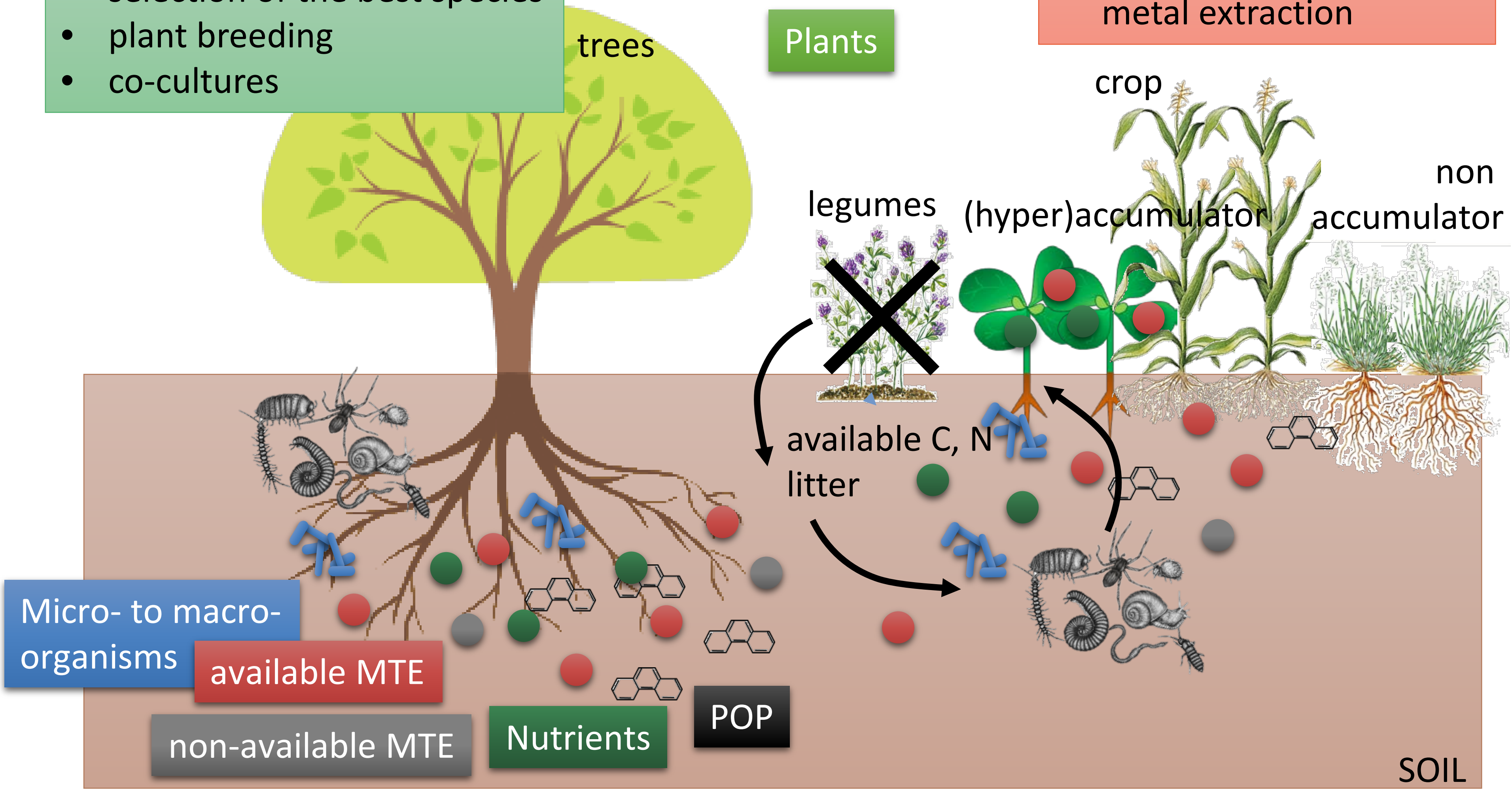
Co-funded by the Erasmus+ Programme of the European Union

Improving phytotechnologies

Valorizing plant properties

- selection of the best species
- plant breeding
- co-cultures

- increased soil fertility
- better nutrient recycling
- better plant growth
- increased/decreased metal extraction

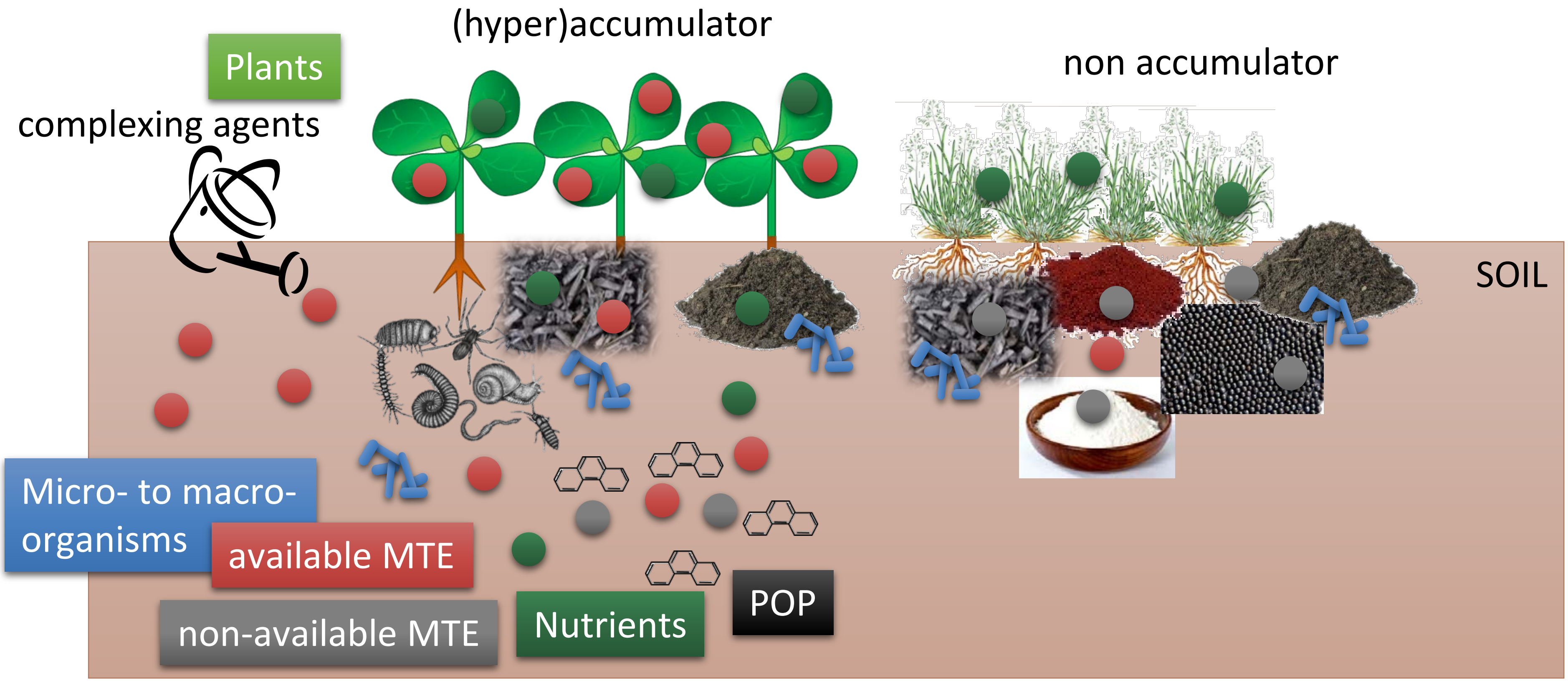


Improving phytotechnologies

Improving soil properties

- organic amendments (compost, biochar…)
- inorganic amendments (Fe oxydes, beringite, zeolite…)
- complexing agents (chelatants, organic acid)

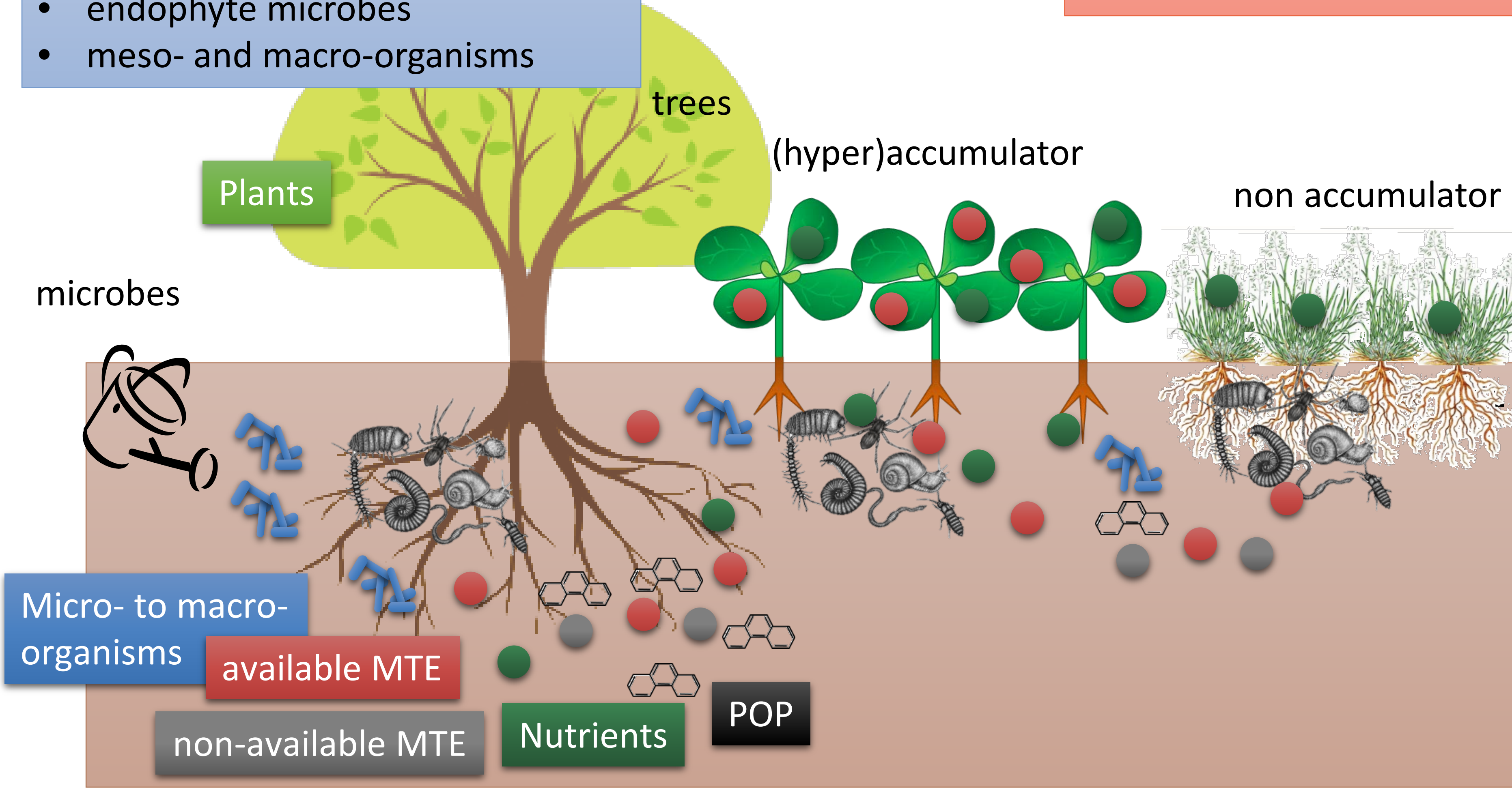
- increased soil fertility
- better nutrient recycling
- better plant growth
- increased/decreased metal extraction



Improving phytotechnologies

Bioaugmentation
- plant growth promoting microbes
- endophyte microbes
- meso- and macro-organisms

- increased soil fertility
- better nutrient recycling
- better plant growth
- increased/decreased metal extraction



Toward new economic developments

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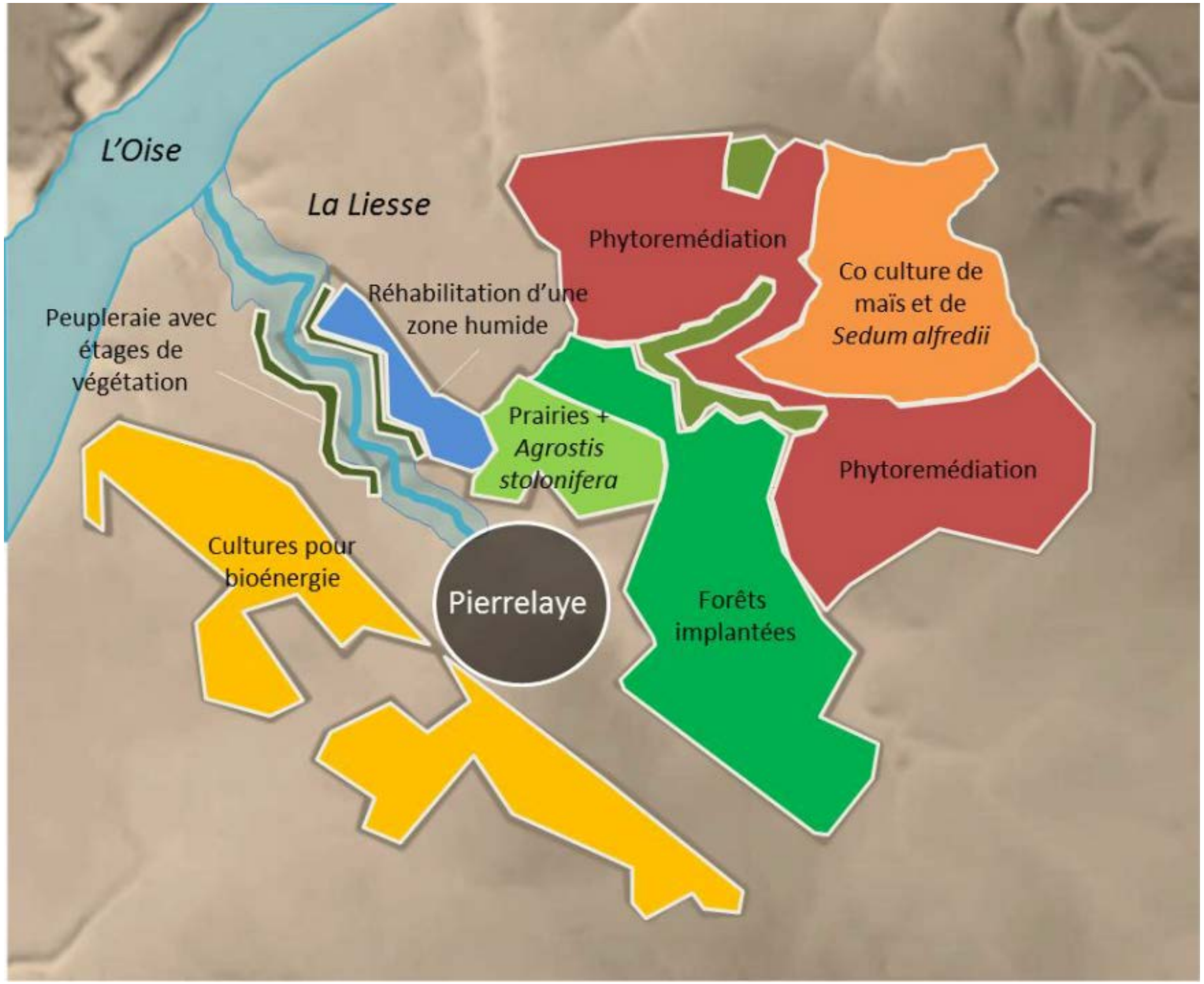
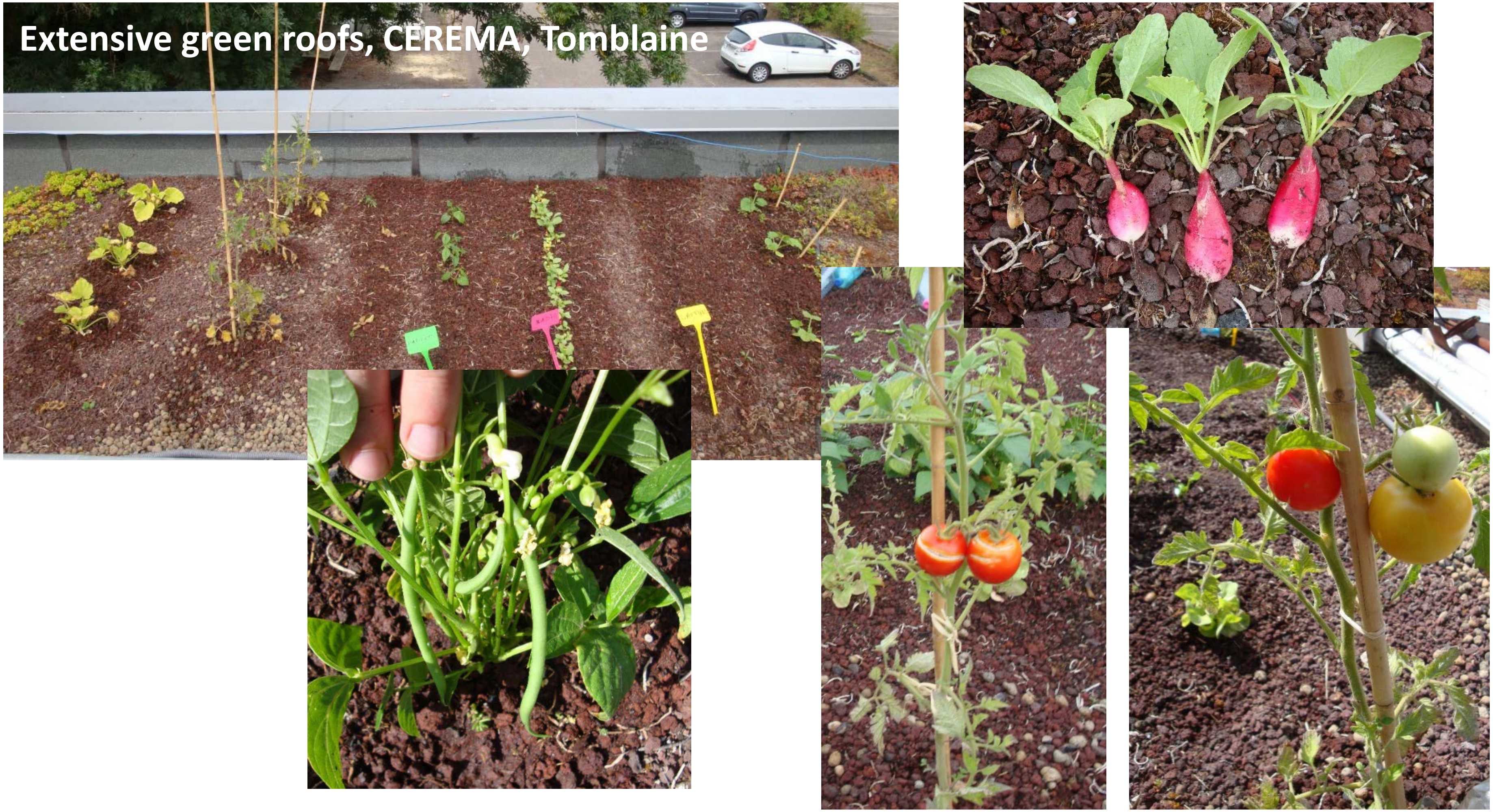
Redevelopment of the plain of Pierrelaye

- Scenario proposed by students



Agrotechnosols

- Cultivating vegetables on urban and industrial soils



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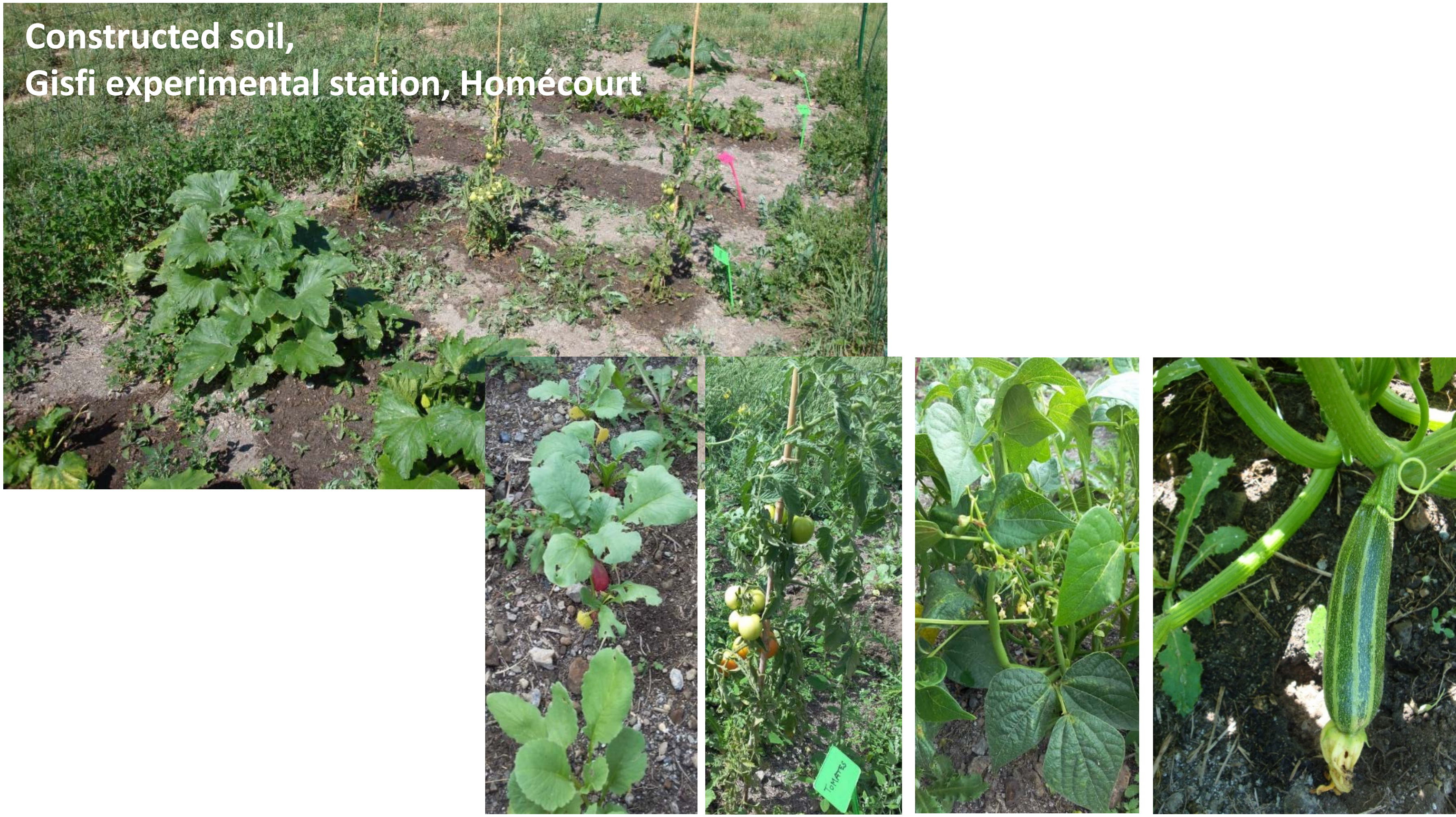


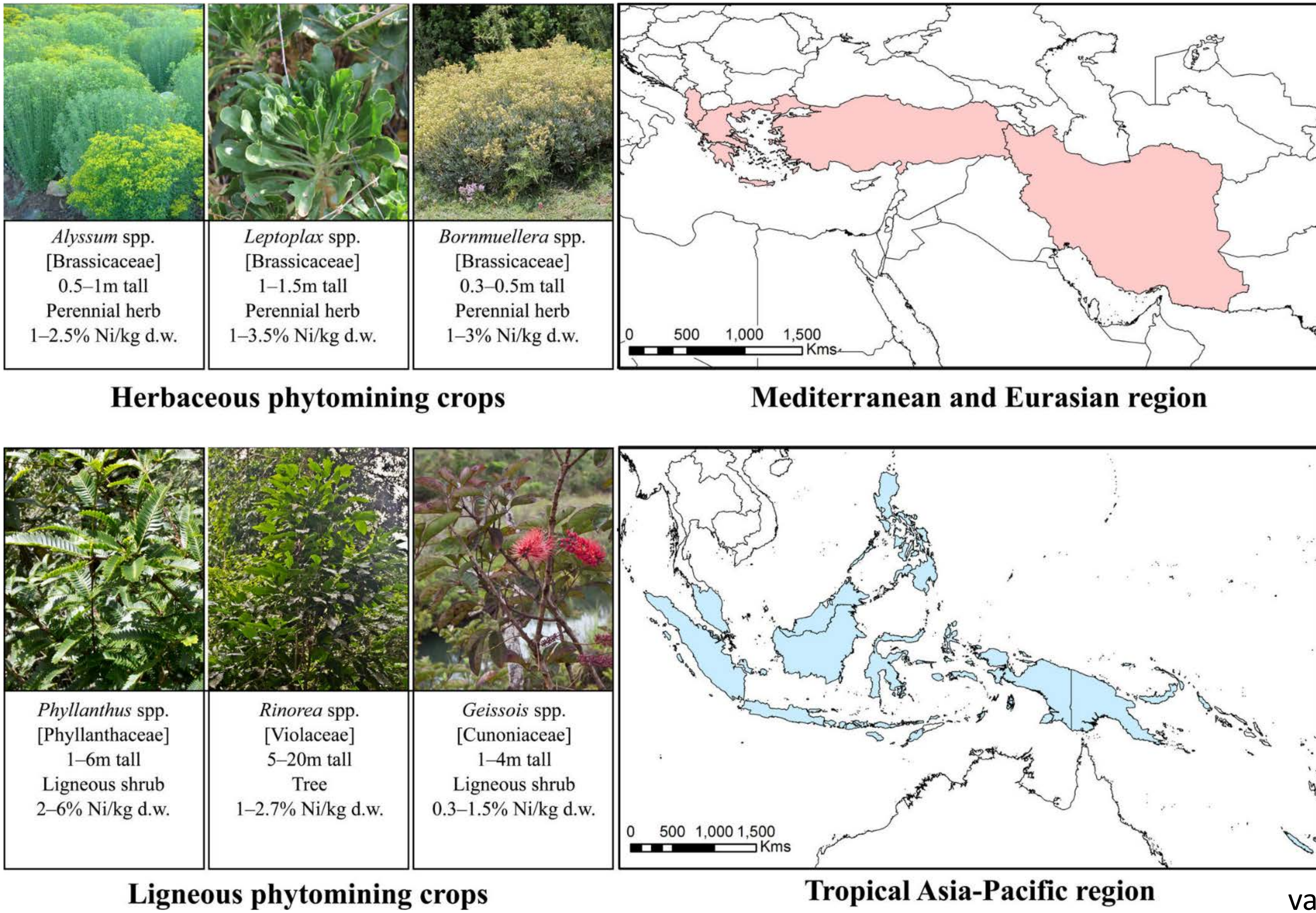
Agromining technologies

- Processing
  - growing hyperaccumulator plants as a crop
    - most efficient using perennial species
  - harvesting biomass
  - drying, ashing and processing it to recover target metals such as Ni
- Two strategies
  - phytomining on degraded or mined land
    - part of the rehabilitation strategy
  - agromining on low-productivity agricultural soils
    - better economic returns to farmers

van der Ent et al. 2015

Agromining technologies

- Global target regionsn and main metal crop genera



van der Ent et al. 2015

Nickel agromining

- Production of ANSH (ammonium nickel sulfate hexahydrate) from *A. murale*

Ni transfer in aqueous phase
- Ashing
- Leaching with acid solutions

Cristallization $Ni(SO_4)_2(NH_4)_2$
- Evaporation
- Addition of $(NH_4)_2SO_4$

Purification
- Salt dissolution
- Addition of NaF and $(NH_4)_2SO_4$