Phytotechnologies: recent experiences in France

1 – Deployment of aided phytostabilisation at field scale: set up and monitoring lessons

2 – Integration of phytotechnologies in cities

Valérie Bert
1 – Deployment of aided phytostabilisation at field scale: set up and monitoring lessons

Specific objectives:

- To reduce environmental risks using aided phytostabilisation (plants and amendments)

- To allow economic valorization of the land through the sale of produced biomass for bioenergy purposes (bioenergy plantation)
SITE DESCRIPTION

- 2 field trials set up in 2011 – sediment landfill sites – national French waterway manager:
  - site A, 1 ha
  - site B, 1 ha
- Contaminated by various organic and inorganic pollutants

<table>
<thead>
<tr>
<th>Parameters (0 – 20 cm depth)</th>
<th>Site A</th>
<th>Site B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture</td>
<td>Silt loam</td>
<td>Loam</td>
</tr>
<tr>
<td>pH (H₂O)</td>
<td>7.6 ± 0.1</td>
<td>7.3 ± 0.1</td>
</tr>
<tr>
<td>CEC (cmol⁺/kg)</td>
<td>17</td>
<td>24</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>5.7</td>
<td>31</td>
</tr>
<tr>
<td>Organic carbon (%)</td>
<td>3.3</td>
<td>15</td>
</tr>
<tr>
<td>Total CaCO₃ (%)</td>
<td>4.0</td>
<td>5.3</td>
</tr>
<tr>
<td>C/N</td>
<td>9</td>
<td>31</td>
</tr>
<tr>
<td>Cd (mg/kg)</td>
<td>11.0 (2.00 – 67.1)</td>
<td>9.74 (6.48 – 15.6)</td>
</tr>
<tr>
<td>Cu (mg/kg)</td>
<td>78.6 (19.6 – 126)</td>
<td>110 (37.7 – 193)</td>
</tr>
<tr>
<td>Pb (mg/kg)</td>
<td>541 (41.5 – 8,154)</td>
<td>956 (146 – 1830)</td>
</tr>
<tr>
<td>Zn (mg/kg)</td>
<td>1,506 (79.0 – 2,710)</td>
<td>6,089 (372 – 12,800)</td>
</tr>
</tbody>
</table>
Site A: SRC poplar plantation (2,200 trees per ha)

April 2011

Field preparation

April 2015

Inoculation of mycorrhizal fungi at the foot of the cuttings

Plantation of poplars cuttings; 2 cultivars: Skado and I214

AIDED PHYTOSTABILISATION + BIOENERGY CROP FOR ECONOMIC VALORIZATION
Site A: SRC poplar plantation

- Skado
- I214
- Skado + alder
- I214 + alder
- Inoculated trees
- Non inoculated trees

Sampled plots:
- Towpath
  - Plot without trees
  - Sampled plots
Site A
Cd accumulation in poplar leaves

Site A

- High Cd concentrations compared to physiological concentrations
  - even in low contaminated zone
  - for both poplars
- Inoculation has no clear effect on Cd accumulation
- Similar Cd accumulation for both poplars
- Seasonal effect?
Site B : VSRC willow plantation (12,000 willows per ha)

- **March 2012**
  - Sowing of grass seeds *(Deschampsia cespitosa)*

- **June 2015**
  - Plantation of willow cuttings;
    - 2 cultivars: Inger and Tordis

- **September - October 2011**
  - Field preparation

- **March 2012**
  - Laying of plastic mulches

- **AIDED PHYTOSTABILISATION**

- **BIOENERGY CROP FOR ECONOMIC VALORIZATION**
Site B : VSRC willow plantation

Plots amended with a basic mineral amendment
- Tordis + grass
- Inger + grass

Untreated plots
- Tordis, bare ground
- Inger, bare ground
- Tordis + grass
- Inger + grass
- Bare ground
- Lime
- Grass
Performance of plants and vegetation dynamics

- Survival rate of trees (Sites A and B)

<table>
<thead>
<tr>
<th>Year</th>
<th>Site A</th>
<th>Site B</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 2014</td>
<td>98 %</td>
<td>73 %</td>
</tr>
<tr>
<td>June 2015</td>
<td>98 %</td>
<td>34 %</td>
</tr>
</tbody>
</table>

- Poplars, April 2015

- Willows, April 2015

- Untreated Plots Survival rate
  - T1: 100 %
  - T2: 81 %
  - T4: 47 %
  - T5: 86 %
Performance of plants and vegetation dynamics

- **Botanical survey (June 2015)**
  - Species richness:
    - Site A: 21 species
    - Site B: 35 species
  - Identification of 5 dominant species: characteristics of wetlands (site B) and forest (site A)

<table>
<thead>
<tr>
<th>Site A</th>
<th>Site B</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Urtica dioica</em></td>
<td><em>Symphytum officinale</em></td>
</tr>
<tr>
<td><em>Glechoma hederacea</em></td>
<td><em>Urtica dioica</em></td>
</tr>
<tr>
<td><em>Ranunculus repens</em></td>
<td><em>Rubus caesius</em></td>
</tr>
<tr>
<td><em>Galium aparine</em></td>
<td><em>Glechoma hederacea</em></td>
</tr>
<tr>
<td><em>Epipactis helleborine</em></td>
<td><em>Ranunculus repens</em></td>
</tr>
</tbody>
</table>

- Potential role of colonizing species in phytostabilisation?
Site B: aided phytostabilisation and willow plantation protocols

September – October 2011

- Plant removal
- Sediment leveling
- Amendment spreading (9t/ha)
- Grass seeds sowing
- Sediment covering
- Willow plantation

Duration of preparation and deployment: 3 weeks
Aided phytostabilisation and willow plantation protocols
TE mapping

Extractable fraction:
- Zn
  - 0 - 0.300
  - 0.301 - 0.516
  - 0.517 - 0.720
  - 0.721 - 0.997
  - 0.998 - 1.47

(Pseudo)total fraction:
- 1220 - 3980
- 3990 - 5720
- 5730 - 7070
- 7080 - 8620
- 8630 - 12800

- Spatial heterogeneity of the pollution
- High concentration values (Cd, Zn)

- No correlation between Zn and Cd extractable and (pseudo-total) concentrations
Aided phytostabilisation \( \Rightarrow \) *Barchampsia cespitosa* as plant cover?

- 100% dense sediment covering
- No toxicity symptoms
- Flowering stage reached
Growth and spread of the invasive species, *Fallopia japonica*, reduced with phytostabilisation.

<table>
<thead>
<tr>
<th>Year</th>
<th>Spot 1 (m²)</th>
<th>Spot 2 (m²)</th>
<th>Total surface (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>90</td>
<td>1,200</td>
<td>1,290</td>
</tr>
<tr>
<td>2013</td>
<td>24</td>
<td>918</td>
<td>942</td>
</tr>
<tr>
<td>2015</td>
<td>16</td>
<td>46</td>
<td>62</td>
</tr>
</tbody>
</table>

- Reduction of the area covered by the Japanese knotweed by 95% (1,228 m²)
- Reduction of the vigour of the plant
- B. cespitosa competes with F. japonica
- Phytostabilisation is a working strategy
Frequent (0.05–0.2 mg kg\(^{-1}\)) and toxic (5–30 mg kg\(^{-1}\)) values (Kabata–Pendias, 2010)

Significant difference between blocks (\(\rho < 0.001\))

→ No amendment effect on Cd shoot concentrations
For Cd, significant differences between blocks ($p < 0.05$)

→ No amendment effect on TE extractable concentrations
Aided phytostabilisation with *Barcampsia cespitosa*?

• Success of the plant cover

• Tolerance to the sediment conditions

• TE concentrations approximate frequent values for grasses on uncontaminated soil

• Growth reduction of the invasive species

⇒ The commercial cultivar, *B. cespitosa*, is a good candidate for phytostabilisation
Aided phytostabilisation with *Optiscor*?

- Until now, no efficiency on the decrease of the TE labile pool and shoot concentrations. Present work is addressing the mechanisms (speciation, OM, CaCO$_3$ stock, etc.).

- Monitoring to be continued the next years
Valuation of the sediment deposit site
→ *Salix* cultivation to produce valuable biomass for bioenergy

*Salix* cultivation in combination with risk management by aided phytostabilisation
Relationship between the grass and the willows

• The grass is competing for water and nutrients

⇒ The survival rate of willows decreases time after time (2013: 90% – 2014: 73%)
⇒ The height and diameter are not increasing, as well as biomass

• Clear evidence when looking at the roots: without versus with the grass
Relationship between the grass and the willows?

April 2015

Untreated and unvegetalized plots

Untreated plots with vegetation cover (tufted hair grass)
TE concentrations in leaves of willows

Cd concentrations >> frequent willow leaves concentrations (<2 mg kg⁻¹ DW) → phytotoxicity?

‘Tordis’ > ‘Inger’

Cd concentrations on amended plots are higher than those on control plots → inefficiency of soil amendment
Lessons after 4 years of monitoring

In our case, the combination of aided phytostabilisation using a grass cover with the plantation of willows to produce biomass for bioenergy is not successful:

• grass and willow competition for water and nutrients

• sensitivity of the selected willow clones to pollution and other factors (willow leaf beetle, herbivores...)

Present work:

⇒ Test other option to avoid grass competition:
  Replace grass by mulch
⇒ Test poplar instead of willow
⇒ Use herbivore protections on trees
PHYTOAGGLO

Integration of phytotechnologies in cities
Polluted soil management
Location of the project

**Phytostabilisation**
- **Set up:** June 2013

**Phytoextraction**
- **Set up:** March 2013
Phytoextraction

- selection of willow
  (*Salix viminalis*) and hyperaccumulating plant
  (*Arabidopsis halleri*)

- significant transfer of Zn and Cd in aerial parts
- metal tolerance

- suitable species with vegetation objective (vegetation area)
pH et concentrations en métaux dans les sols

- alcaline pH (8,09 ± 0,17) a priori not optimal for phytoextraction
- spatial heterogeneity of the pollution(Cd, Zn et Pb)
June 2015 willow plantation—successful growth
June 2015 – metal concentration in willow leaves

• Zn and Cd accumulation at non physiological levels (Zn > 200; Cd > 0.5)

• higher metal concentration in 2015 than in 2014 (1.5 times more Cd and 1.6 times more Zn)

• BCF: foliar concentration / soil concentration
  BCF ~ 2.5 interest for phytoextraction
  (accumulating behavior)
in situ growth of A. halleri

27 mai

20 July

23 September

1er July

Growth
Flowering stage
TE concentrations in A. halleri

- A. halleri concentration > willow concentration (Cd: 4.2; Zn: 1310 mg/kg PS)
- Interest of the co-culture willow/A. halleri
Do snails eat A. halleri or willows?

Snails in contact with plants more/less enriched with Zn and Cd
Regular weight measurement

A. Halleri Auby (enriched Zn/Cd: C+) vs control (C–)
Willows phytoagglo (enriched Zn/Cd: C+) vs control (C–)
Conclusions after 2 years of monitoring

Phytoextraction

• Success of the willow plantation (growth and vegetation image)

• Success of the A. halleri growth

Besides the alcaline pH:
• increase of foliar accumuation of Cd/Zn in willows
• Zn/Cd foliar accumulation in A. halleri better than willow

Present work
† Continuation of monitoring
† Increase phytoextraction performance by collecting leaves of willows
Willow leaves collection – production of Zn ecocatalyst (green chemistry– Phytochem project)