ORGANIC AMENDMENTS FOR TRACE ELEMENTS
CHEMICAL/PHYTO STABILIZATION IN SOILS:
CASES FROM PORTUGAL

PAULA ALVARENGA

LEAF – Linking Landscape, Environment, Agriculture and Food Research Unit
Instituto Superior de Agronomia (School of Agriculture),
University of Lisbon, Portugal palvarenga@isa.ulisboa.pt
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1. INTRODUCTION / MOTIVATIONS

Mining was an important activity for the socioeconomic development of many countries, but it gave rise to the appearance of large areas, with:

- Abnormally acid soils,
- High levels of potentially toxic trace elements (e.g., As, Cu, Pb, Zn),
- Poor nutritional conditions
- Scarce vegetation.

Overview of three mining areas in the Portuguese sector of the Iberian Pyrite belt (IPB)

Lousal

Aljustrel

São Domingos
1. INTRODUCTION / MOTIVATIONS

These contaminated soils are prone to erosion, by wind and water, which only contributes to the enlargement of the contaminated area, both affecting soils and receiving waters.
1. INTRODUCTION / MOTIVATIONS

But, are mining activities representative of soil contamination?


Distribution of sectors contributing to soil contamination in Europe

- Waste disposal and treatment: 37.1%
- Industrial and commercial activities: 33.2%
- Storage: 10.5%
- Transport spills on land: 7.9%
- Others: 7.9%
- Nuclear operations: 0.1%
- Military: 3.4%

It takes a smaller number of mining enterprises to contribute to 1% industrial contamination.
Heavy metals (potentially toxic trace elements) are the main contaminant affecting soils in Europe.

Soil contamination with heavy metals may have origin in other anthropogenic source (e.g., industrial activities and waste disposal and treatment).

It is important to deal with soil contamination to improve:
• Public health
• Environmental quality (soil and water)
• Land regeneration
• Sustainable use of soils

Overview of contaminants affecting soils

- Heavy metals 34.9%
- PAHs 10.9%
- Mineral oil 23.9%
- CHCs 8.3%
- PAHs 10.9%
- Others 9.3%
- Phenols 1.3%
- Cyanides 1.1%

What is the solution for contaminated mining sites?
Phytostabilization exploits the properties of indigenous and naturally-selected metal-tolerant plants to revegetate metal-contaminated substrates.

Stabilization is both physical and through the indirect rhizosphere effects of root systems and the interaction with soil microflora in chemically stabilizing bioavailable metal fractions.

The process establishes a pathway to long-term ecological restoration of sites, so allowing the re-establishment of ecosystem services.
2. PHYTOSTABILIZATION

In order to succeed in the restoration of a plant cover on these sites, **metal-tolerant species** should be used.

Some plant species **immobilize the contaminants in soil** through their:
- absorption and accumulation by the roots,
- adsorption onto the roots,
- precipitation of metals in the root zone.

This **reduction in the mobility of contaminants** prevents:
- The potential migration of contaminants by wind erosion;
- The transport of surface soil exposed to erosion;
- The leaching of soil contaminants to groundwater; and
- Trace elements bioavailability to enter the food chain.
2. PHYTOSTABILIZATION

This technology can be used to restore a plant cover in areas where natural vegetation is sparse due to high metal concentrations in surface soils or physical disturbance of the surface materials.

**Plant characteristics** that make them ideal to be used in a phytostabilization process:

- Tolerance to high concentrations of the contaminant in question;

- High root biomass production, able to immobilize the contaminants by absorption, precipitation or reduction;

- Retention of contaminants in the roots, in opposition to its transfer to the sheets, to avoid having to deal with these plant material as a residue and to minimize metal transfer to the food chain.

But how is it possible to establish a plant cover in such a harsh environment?
The application of **organic and/or inorganic amendments** to these soils can promote the re-establishment of a vegetative cover by:

- raising the pH,
- increasing the soil organic matter content,
- adding essential nutrients for plant growth,
- increasing water holding capacity, aggregate stability, and
- rendering the metals less soluble/bioavailable by shifting them from “plant-available” forms to fractions associated with organic matter, carbonates or metal oxides.

**Phytostabilization + organic amendments = Assisted-Phystostabilization**

Can we use organic wastes as soil amendments?
4. WASTES AS SOIL AMENDMENTS

In 2008, the European Waste Framework Directive (2008/98/EC) introduced the concept of waste hierarchy, by which the waste disposal at a landfill should be the last option to be taken, and only if its reduction, reuse, or valorization are not possible.

This Directive could be intended as one of the means to attain a sustainable growth, that the European Union (EU) has identified as one of its major priorities (European Commission, 2010).

Circular economy: wastes should be reintegrating in the productive cycle, keeping the added value of products for as long as possible. In this way:
• The use of scarce resources is reduced;
• A product can generate further value, by keeping resources within the economy, productively using them again and again;
• The main aim of eliminating “waste” is achieved, reducing landfill disposal.
4. WASTES AS SOIL AMENDMENTS

In this case, using organic wastes as soils amendments allows the increase on soil OM content (soil C sequestration) and the integration of nutrients (e.g., N, P, K) into the biogeochemical cycles.

By keeping organic wastes away from landfills, their organic matter and nutrients can be recycled, less methane is emitted, and leachates produced are less polluted.
However, amending the soil with organic wastes can:

- Introduce in the soil undesirable elements and/or composites (e.g. heavy metals or organic pollutants),
- This is of particular concern in the case of composites produced from mixed municipal solid waste (MMSWC), because there is no source separation of the waste materials…
- … or in the case of sewage sludge (SS) from wastewater plants treating large amounts of industrial effluents.
… metals/metaloids can be mobilized in the soil, assimilated by the plants, or leached by the runoff waters.

… those metals or composts can be highly bioavailable, promoting an increase in the soil toxicity.

Contradictory effects have been reported for metal(loid) mobility as a response to different soil organic amendments.

**IMPORTANT:** evaluate the potential risks in order to correctly choose management / remediation strategies!
According to existing **legislation and guidelines**, to evaluate if a soil is contaminated, total concentration of contaminants (in this case potentially toxic trace elements) should be determined, and their concentrations compared with limit values…

... if their **total concentration are above limit values**, the soil is considered contaminated and should be submitted to a clean-up process.

However, in soil phyto(stabilization) strategies, total concentrations of the contaminants, at least trace elements, do not decrease.

In this perspective, if the effectiveness of the remediation process is only evaluated by such a “simple” approach, it would be impossible to evidence the benefits of the remediation process – **improvement in soil functionality and productivity**.
5. HOW TO ASSESS THE BENEFITS / RISKS?

Chemical parameters are important to assess the improvement in soil quality: pH, EC, soil OM, soil N (total and extractable), available P and K...

... and physical parameters could also be used: texture, bulk density, water holding capacity, infiltration, aggregate stability...

Total potentially toxic trace elements concentrations are important to evaluate risk (soil + waste amendment)...

... and the extractable fraction of those potentially toxic trace elements are also important:

- mobile / effective bioavailable (extracted by 0.01 M CaCl$_2$).
- mobilizable / potentially bioavailable (extracted by 0.5 M NH$_4$CH$_3$COO, 0.5 M CH$_3$COOH and 0.02 M EDTA, pH 4.7).
5. HOW TO ASSESS THE BENEFITS / RISKS?

But soil biological properties should be included in the risk/benefit evaluation of every remediation process:

- Microbial biomass C and N;
- Microbial functional and structural activity;
- Potentially mineralizable N;
- Soil respiration;
- **Soil enzymatic activities**: dehydrogenase, as an overall indicator of microbial activity, and some exoenzymes, important in some nutrients cycles (β-glucosidase, cellulase, urease, protease and acid- and basic-phosphatase);
- **Plant bioassays**;
- **Ecotoxicological bioassays** using the whole soil (to evaluate soil habitat function, e.g., with earthworms) and bioassays with soil-water extracts (to evaluate soil retention function, e.g., luminescent inhibition of *Vibrio fischeri*, *Daphnia magna* immobilization).
6. WHICH WASTES?

MIXED MUNICIPAL SOLID WASTE COMPOST (MMSWC)

GREEN WASTE-DERIVED COMPOST (GWC)

Composting is the most recommended option to stabilize wastes and recover their OM content

SEWAGE SLUDGE (SS)

Mostly used in agricultural soil without treatment or sent to landfill
6. WHICH WASTES?

**DRINKING-WATER TREATMENT RESIDUES (DWTR)**

- Biomass ash (from the combustion of forest residues)
  - Always sent to landfill
- Cellulosic sludge
  - Used by local farmers and by the paper mill in *Eucalyptus* cultivation

**WASTES FROM THE PULP AND PAPER INDUSTRY**
7.1. Experiments with MMSWC, GWC and SS

Greenhouse pot experiments
Objectives: The aim of the study was to assess the effect of MMSWC, SS and of a green waste-derived compost (GWC) as immobilizing agents in assisted phytostabilization of a soil affected by mining activities (Aljustrel mining area, a pyrite mine located in SW Portugal in the Iberian Pyrite Belt), evaluating:

(i) soil physico-chemical characteristics,

(ii) Cu, Pb and Zn pseudo-total and bioavailable fractions,

(iii) plant relative growth,

(iv) soil enzymatic activities, and

(v) soil ecotoxicological characteristics.

(Alvarenga et al., 2008, 2009a, 2009b)
Soil and organic residues characteristics:

Table. Soil and organic residues characteristics (mean values, n = 3).

The organic residues had total metal contents below the limits established by official guidelines for SS (Directive 1986/278/EE), allowing their use in agricultural soils.

(Alvarenga et al., 2008, 2009a, 2009b)
7.1. Experiments with MMSWC, GWC and SS

**Greenhouse pot experiment** (3 kg/pot): organic amendments application rate: 25, 50 and 100 Mg ha\(^{-1}\) (DM basis, 3 replicates);

Incubation period: 28 d, 70% WHC. After that, the pots were sown with perennial ryegrass (*Lolium perenne* L.) and grown for 60 d.

**Soil Properties:** pH, EC, soil OM, soil N, available P and K

**Cu, Pb and Zn concentrations:**
- pseudo-total (aqua regia digestion)
- mobile / effective bioavailable (extracted by 0.01 M CaCl\(_2\), pH 5.7, without buffer)
- mobilisable / potentially bioavailable (extracted by 0.5 M NH\(_4\)CH\(_3\)COO, 0.5 M CH\(_3\)COOH and 0.02 M EDTA, pH 4.7).

**Soil enzymatic activities:** Dehydrogenase, β-glucosidase, cellulase, urease, protease and acid phosphatase.

**Soil ecotoxicity:** Indirect acute bioassays using soil leachates: luminescent inhibition of *Vibrio fischeri* and *Daphnia magna* immobilization.
7.1. Experiments with MMSWC, GWC and SS

Effects on soil chemical properties

- Significant increase in **pH and soil salinity**, more pronounced in the case of SS and MMSWC application.
- Both composts were equivalent in their capacity to raise soil OM, but SS application led to better results.
- Significantly different capacity to supply essential macronutrients (N, P, K)...

(Alvarenga et al., 2008, 2009a, 2009b)
## 7.1. Experiments with MMSWC, GWC and SS

### Effects on soil metal concentrations

Table. Mean values (mean, n = 3, n = 9 for the control, Tukey test, p < 0.05).

Cu, Pb and Zn **pseudo-total concentrations** did not change significantly, when compared to the control soil.

The organic residues tested were effective in the *in situ* immobilization of Cu, Pb and Zn, lowering their **mobile fractions**.

Cu and Zn **mobilisable fractions** increased with MMSWC and SS application and the opposite was true following amendment with GWC.
7.1. Experiments with MMSWC, GWC and SS

Effects on *L. perenne* relative growth

The greatest increase was obtained in the presence of 50 Mg MMSWC ha\(^{-1}\), followed by SS at the same application rate.

The relative growth observed with GWC application was not significantly different from that obtained in the mine soil - GWC was less capable of correcting soil acidity and supplying essential macronutrients (N, P, K).

An impaired growth was registered when using 100 Mg ha\(^{-1}\) of both SS and MMSWC that, in the case of SS application, was very notorious – secondary salinization???

**Figure** – Relative growth of perennial ryegrass (mean±SD, n = 3, n = 9 for the control).
7.1. Experiments with MMSWC, GWC and SS

Effects on soil enzymatic activities

Application of SS led to the greatest values of dehydrogenase, acid phosphatase, β-glucosidase, protease and urease activities, corresponding to the greatest overall microbial and biochemical activity in amended soils.

Conversely, GWC did not increase these enzymatic activities, relative to the unamended soil.

(Alvarenga et al., 2008, 2009a, 2009b)
###Effects on soil ecotoxicity

All the organic amendments were able to suppress soil toxicity to levels that did not affect *D. magna*, when applied at 50 and 100 Mg ha\(^{-1}\), but …

… SS, at the same application rates, increased the soil leachate toxicity towards *V. fischeri*.

**Table.** Acute toxicity of soil leachates towards *D. magna* and *V. fischeri* (EC\(_{50}\), n = 6 in the luminescent inhibition bioassay, n = 12 in the *D. magna* immobilization bioassay).

<table>
<thead>
<tr>
<th>Organic amendment (Mg ha(^{-1}))</th>
<th>(\text{EC}_{50}) (control soil)</th>
<th>(\text{EC}_{50}) (MMSWC)</th>
<th>(\text{EC}_{50}) (GWC)</th>
<th>(\text{EC}_{50}) (SS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control soil</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>MMSWC</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>GWC</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>SS</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
</tr>
</tbody>
</table>

(Alvarenga et al., 2008, 2009a, 2009b)
CONCLUSIONS

The crosschecking of the chemical and ecotoxicological data allows us to conclude that the SS toxic responses could not be imputed neither to the increase in soil salinity, nor to the Cu, Pb and Zn contents, whose soluble/mobile concentrations decreased as a consequence of the treatments.

Likely they derived from other, non identified, toxic compounds (e.g. organic xenobiotics like PCBs, PAHs) that compromise its use in soils, or to the fact that the sludges were not stabilized.

This study showed the importance of an integrated evaluation of soil quality on remediation processes:

- although SS immobilized trace metals and corrected soil acidity, improving soil biochemical status….

- … when used at high application rates led to toxicity of soil leachate towards V. fischeri, decreased soil cellulase activity and impaired ryegrass growth.
7.1. Experiments with MMSWC, GWC and SS

MMSWC, applied at 50 Mg ha\(^{-1}\), was an effective amendment to be used in the immobilization of metals, allowing the greatest increase in plant biomass, and improving the soil chemical, microbial, biochemical, and ecotoxico logical status.

**Disadvantage:** high salinity, high metal content...

GWC has low salinity and low metal content.

**Disadvantage:** GWC was not as effective as the other compost to correct soil acidity, and to its lower contents of N, P and K.

*Perennial ryegrass* seems appropriate to be used in aided phytostabilization programs.

**Disadvantage:** high Pb concentrations found in the shoots increases the risk of metal transfer to the food chain.

(Alvarenga et al., 2008, 2009a, 2009b)
7.2. Experiments with MMSWC and GWC

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The Effect of Compost Treatments and A Plant Cover with Agrostis tenuis on the Immobilization/Mobilization of Trace Elements in a Mine-Contaminated Soil

P. Alvarenga a d, A. de Varennes b c & A. C. Cunha-Queda b d

a DCTA—Instituto Politécnico de Beja, Escola Superior Agrária, Rua Pedro Soares, Beja, Portugal
b DQAA—Instituto Superior de Agronomia, TU Lisbon, Tapada da Ajuda, Lisboa, Portugal
c CEER—Instituto Superior de Agronomia, TU Lisbon, Tapada da Ajuda, Lisboa, Portugal
d UIQA—Instituto Superior de Agronomia, TU Lisbon, Tapada da Ajuda, Lisboa, Portugal

(Alvarenga et al., 2014)
Objectives: The aim of the study was to assess the effect of mixed municipal solid waste compost – MMSWC -, and of a green waste-derived compost – GWC, supplied with mineral fertilization and a liming agent - as immobilizing agents in assisted phytostabilization of a soil affected by mining activities, in semi-field conditions (outdoors conditions), evaluating:

(i) soil physico-chemical characteristics,

(ii) As, Cu, Pb, and Zn pseudo-total and mobile fractions,

(iii) plant relative growth, and

(iv) soil enzymatic activities.

(Alvarenga et al., 2014)
7.2. Experiments with MMSWC and GWC

SEMI-FIELD EXPERIMENT SET-UP:
±60 kg soil/container, outdoors.

.Control soil

MMSWC (50 Mg ha⁻¹)
+ CaO,
+ N, P, K fertilization

7.2. Experiments with MMSWC and GWC

✓ 28 d after composts application, 4 of the containers were sown with highland bent (*Agrostis tenuis* Sibth), occasionally watered.
✓ Plants were collected 90 d after sowing.

(Alvarenga et al., 2014)
7.2. Experiments with MMSWC and GWC

- **Soil properties**
  - pH, EC, soil OM, soil N, available P and K

- **As, Cu, Pb and Zn concentrations**
  - pseudo-total (aqua regia digestion)
  - mobile / effective bioavailable (extracted by 0.01 M CaCl$_2$, pH 5.7, without buffer)

- **Soil enzymatic activities**
  - Dehydrogenase (indicator of overall microbial activity), β-glucosidase, and acid phosphatase.

- **Plant**
  - Relative growth, and
  - Metal concentrations (above ground material).
7.2. Experiments with MMSWC and GWC

Effects on soil chemical characteristics

- Both treatments allowed the necessary acidity correction, without a significant increase in soil salinity.

- Equivalent capacity to raise soil OM.

- The levels of available P and K were not significantly different between the treatments, but there were still significant differences in the N content in the soil.

(Alvarenga et al., 2014)
Effects on soil enzymatic activities

Amended soil evidenced higher soil enzymatic activities, especially in the containers where the plants have grown, but...

... the differences were only significant in some cases, mainly following the application of MMSWC and sowing the soil with *A. tenuis*.

(Alvarenga et al., 2014)
7.2. Experiments with MMSWC and GWC

Effects on Agrostis tenuis yield

High phytotoxic effect in the non-amended soil, with negligible plant growth.

Biomass accumulation was higher in the soil amended with GWC+lime+mineral fertilization.

Figure – Plant yield (mean±SD, n = 4, Tukey test, p < 0.05).
7.2. Experiments with MMSWC and GWC

Effects on soil metal concentrations

- Pseudo-total As, Cu, Pb and Zn did not increase as a consequence of the organic residues application (data not shown).
- Both treatments led to a decrease in the effective bioavailable Cu.
- Only GWC+lime+mineral fertilization was able to significantly decrease effective bioavailable Zn.

**Figure** – Mobile/effective bioavailable Cu and Zn fractions (mean±SD, n = 4, Tukey test, p < 0.05). % of the total = mobile concentration / pseudo-total metal concentration*100

(Alvarenga et al., 2014)
**7.2. Experiments with MMSWC and GWC**

**Effects on soil metal concentrations (cont.)**

- Effective bioavailable Pb was quite low, even in the control soil (≈ 1% of the total), and was not affected by the organic residues addition...

**Figure** – Mobile/effective bioavailable Pb fraction (mean±SD, n = 4, Tukey test, p < 0.05). % of the total = mobile concentration / pseudo-total metal concentration*100

(Alvarenga et al., 2014)
Effects on soil metal concentrations (cont.)

✓ Effective bioavailable As increased, more than 3 times, as a consequence of the raise in the pH accomplished by the soil amendment…

… but the effective bioavailable As fraction was a very small fraction of the pseudo-total As content!

![Graph showing mobile/effective bioavailable As fraction](image)

Figure – Mobile/effective bioavailable As fraction (mean±SD, n = 4, Tukey test, p < 0.05). % of the total = mobile concentration / pseudo-total metal concentration*100

(Alvarenga et al., 2014)
7.2. Experiments with MMSWC and GWC

**Effects on plant metal concentrations**

Metal concentrations in the plant were not significantly different when different soil amendments were applied and…

… they are lower than **domestic animals toxicity limits**.

AF(As), AF(Cu) and AF(Pb) $<< 1$; and AF(Zn) $< 1 \rightarrow$ indicating that the *A. tenuis* is useful for phytostabilization.

**Table.** Plant metal concentrations and accumulation factors (mean, $n = 4$, Tukey test, $p < 0.05$).
CONCLUSIONS

MMSWC, applied at 50 Mg ha\textsuperscript{-1}, evidenced as an effective amendment to be used in the assisted phytoremediation of this type of mine soil, correcting its major constraints, and allowing the establishment of a plant cover.

Although GWC, alone, was not as effective as MMSWC in the soil correction (Alvarenga et al., 2008, 2009a, 2009b), if the soil was additionally limed and if mineral fertilizers were applied, the results can be similar or better to the ones obtained with the MMSWC application.

Both Cu and Zn were effectively immobilized by the amendments tested, however…

… As extractability was enhanced by the amendments application, presumably connected to the raise in soil pH. However, effective bioavailable/mobile As fraction remained as a small fraction of the pseudo-total metal content.

*Agrostis tenuis* can be used in the assisted phytostabilization of this type of mine soil, as it as prevented As, Cu, Pb and Zn to reach high concentrations in its edible parts, minimizing their transfer into the food chain.
7.3. Experiments with DWTR

**Objectives:** The aim of this study was to evaluate the use of drinking-water treatment residuals (DWTR), from the Roxo drinking-water treatment plant (Alentejo – Portugal), in the organic amendment of a soil affected by mining activities (Aljustrel mine, Iberian Pyrite Belt), using perennial ryegrass (*Agrostis tenuis* Sibth).
7.3. Experiments with DWTR

Table. Characterization of the drinking-water treatment residuals (DWTR) used as organic amendment (mean value ± standard-deviation, n=3).

<table>
<thead>
<tr>
<th>Agronomic parameters</th>
<th>DWTR</th>
<th>Legal limits(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter (%)</td>
<td>19.0 ± 0.2</td>
<td>-</td>
</tr>
<tr>
<td>pH</td>
<td>6.7 ± 0.0</td>
<td>-</td>
</tr>
<tr>
<td>EC (mS cm(^{-1}))</td>
<td>0.92 ± 0.02</td>
<td>-</td>
</tr>
<tr>
<td>OM (%)</td>
<td>57.5 ± 0.1</td>
<td>-</td>
</tr>
<tr>
<td>N (%)</td>
<td>0.63 ± 0.08</td>
<td></td>
</tr>
<tr>
<td>P (g P(_2)O(_5) kg(^{-1}) DM)</td>
<td>&lt;6</td>
<td></td>
</tr>
<tr>
<td>K (g K(_2)O kg(^{-1}) DM)</td>
<td>490 ± 16</td>
<td></td>
</tr>
<tr>
<td>Ca (g kg(^{-1}) DM)</td>
<td>295.0 ± 5.5</td>
<td>-</td>
</tr>
<tr>
<td>Mg (g kg(^{-1}) DM)</td>
<td>6.2 ± 0.1</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Metals</th>
<th>DWTR</th>
<th>Legal limits(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd (mg kg(^{-1}) DM)</td>
<td>1.8 ± 0.1</td>
<td>20</td>
</tr>
<tr>
<td>Cr (mg kg(^{-1}) DM)</td>
<td>&lt;6.67</td>
<td>1000</td>
</tr>
<tr>
<td>Cu (mg kg(^{-1}) DM)</td>
<td>20.4 ± 0.4</td>
<td>1000</td>
</tr>
<tr>
<td>Hg (mg kg(^{-1}) DM)</td>
<td>0.05 ± 0.00</td>
<td>16</td>
</tr>
<tr>
<td>Ni (mg kg(^{-1}) DM)</td>
<td>18.2 ± 0.5</td>
<td>300</td>
</tr>
<tr>
<td>Pb (mg kg(^{-1}) DM)</td>
<td>2.7 ± 1.2</td>
<td>750</td>
</tr>
<tr>
<td>Zn (mg kg(^{-1}) DM)</td>
<td>28.9 ± 0.8</td>
<td>2500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pathogenic microorganisms</th>
<th>DWTR</th>
<th>Legal limits(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Escherichia coli (CFU g(^{-1}))</td>
<td>&lt; 10</td>
<td>&lt; 1000</td>
</tr>
<tr>
<td>Salmonella spp (Present/Absent 50 g(^{-1}))</td>
<td>Absent</td>
<td>Absent 50 g(^{-1})</td>
</tr>
</tbody>
</table>

\(^a\) Law-Decree N.º 276/2009.

- Neutral characteristics (pH 6.7), important to reduce trace elements bioavailable fraction;
- High OM content (57.5 % DM), which makes it interesting to improve soil OM;
- Low values for some nutrients, like N and P;
- Trace elements and pathogenic indicator microorganisms content are below the limit values established by law.
7.3. Experiments with DWTR

Soil form the Aljustrel mine (IPB): very acidic (pH 3.05), with high electrical conductivity (EC 3.65 mS cm\(^{-1}\)), low OM content (5.3 g kg\(^{-1}\) DM), and high trace element content (296.9 mg Cu kg\(^{-1}\), 381.7 mg Pb kg\(^{-1}\) and 1232.0 mg Zn kg\(^{-1}\), DM).

Previous incubation assay: with different doses of DWTR (6, 12, 24, 48 and 96 t DM ha\(^{-1}\)), with and without lime application (CaCO\(_3\) 11 t ha\(^{-1}\)).

<table>
<thead>
<tr>
<th>DWTR (t ha(^{-1}))</th>
<th>CaCO(_3) (t ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>

- The highest dose of sludge (96 t DM/ha), caused a two-fold increase in the soil OM content and a decrease in its salinity.
- The increase in the soil pH was more pronounced with the simultaneous application of CaCO\(_3\).
- Significant decrease in the Cu and Zn CaCl\(_2\) 0.01M extractable content (extractable Pb < LD =1.67 mg kg\(^{-1}\)).

(Alvarenga et al., 2018)
7.3. Experiments with DWTR

**POT EXPERIMENT:**

- In pots with 3 kg of soil,
- DWTR application rate: 48, 96, and 144 t DM/ha,
- With and without lime application: CaCO$_3$ 11 t DM/ha,
- *Agrostis tenuis* (250 kg seeds/ha) was seeded one week after,
- Four replicates per treatment,
- Three months growing, outdoors, occasionally watered.

**RESULTS WERE ASSESSED EVALUATING:**

- **PLANT PARAMETERS:** Biomass and total metal content (Cu, Pb and Zn).
- **SOIL AGRONOMICAL CHARACTERIZATION:** pH(H$_2$O), EC, OM, N$_{Kjeldahl}$, available P and K.
- **TOTAL TRACE ELEMENTS IN SOILS (Cu, Pb and Zn):** aqua-regia digestion
- **EXTRACTABLE TRACE ELEMENTS IN SOILS (Cu, Pb and Zn):** extracted by 0.01 M CaCl$_2$;
- **SOIL ENZYMATIC ACTIVITIES;**
- **SOIL-WATER EXTRACT TOXICITY** using different aquatic organisms.

(Alvarenga et al., 2018)
7.3. Experiments with DWTR

Effects of the treatments on soil characteristics

Figure – Effects of the treatment on soil characteristics (mean±SD, n=4). Values marked with the same letter are not significantly different (Tukey HSD test, P>0.05)

(Alvarenga et al., 2018)
7.3. Experiments with DWTR

Effects of the treatments on soil trace elements extractability

**Figure** – Effects of the treatment on Cu and Zn extractable faction (mean±SD, n=4 ). Values marked with the same letter are not significantly different (Tukey HSD test, P>0.05).

- Significant decrease in the **Cu and Zn extractable content**.
- **Extractable Pb** was very low (< LD =1.67 mg kg$^{-1}$), even before the treatment.

(Alvarenga et al., 2018)

P. ALVARENGA
7.3. Experiments with DWTR

Effects on plant parameters

- Plants germinated but died in the pots without amendment, and in the pots amended with 48 t ha\(^{-1}\) without lime.
- The other combinations of amendments allowed the establishment of a plant cover.

Concentrations in the shoots with the application of 144 t DWTR ha\(^{-1}\) (average, n=8)

- \([\text{Cu}] = 34 \pm 5 \text{ mg kg}^{-1} \text{ DW}\)
- \([\text{Pb}] = 24 \pm 12 \text{ mg kg}^{-1} \text{ DW}\)
- \([\text{Zn}] = 477 \pm 259 \text{ mg kg}^{-1} \text{ DW}\)

Concentrations in contaminated plants (Kabata-Pendias and Pendias (1984))

- 20 – 100 mg kg\(^{-1}\) DW
- 30 – 300 mg kg\(^{-1}\) DW
- 100 - 400 mg kg\(^{-1}\) DW
7.3. Experiments with DWTR

Table. Soil water-extract characteristics: pH, electrical conductivity (EC; mS cm\(^{-1}\)) (mean ± standard-deviation, n=3), and ecotoxicological responses calculated as EC\(_{50}\) values (mean values % v/v; 95% confidence interval, CI; n=2 for V. fisheri, and n=3 for T. platyurus and D. magna).

<table>
<thead>
<tr>
<th>DWTR (t ha(^{-1}))</th>
<th>CaCO(_3) (t ha(^{-1}))</th>
<th>Soil water-extract pH</th>
<th>Soil water-extract EC</th>
<th>V. fisheri 30 min-EC(_{50})</th>
<th>T. platyurus 24h-EC(_{50})</th>
<th>D. magna 48h-EC(_{50})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>2.8±0.0</td>
<td>2.14±0.16</td>
<td>43.2 (42.4-44.0)</td>
<td>0.5 (0.4-0.6)</td>
<td>5.1 (3.0-7.0)</td>
</tr>
<tr>
<td>0</td>
<td>11</td>
<td>4.9±0.5</td>
<td>1.35±0.06</td>
<td>nt</td>
<td>2.2 (1.8-2.8)</td>
<td>4.0 (1.8-5.7)</td>
</tr>
<tr>
<td>48</td>
<td>0</td>
<td>4.2±0.0</td>
<td>1.90±0.17</td>
<td>27.2 (27.0-27.5)</td>
<td>0.4 (0.3-0.5)</td>
<td>4.7 (2.6-6.6)</td>
</tr>
<tr>
<td>48</td>
<td>11</td>
<td>5.9±0.4</td>
<td>1.40±0.03</td>
<td>53.6 (53.4-53.8)</td>
<td>21.6 (9.9-31.8)</td>
<td>nt</td>
</tr>
<tr>
<td>96</td>
<td>0</td>
<td>4.8±0.3</td>
<td>1.35±0.06</td>
<td>nt</td>
<td>12 (7.7-16.2)</td>
<td>22.0 (17.0-19.5)</td>
</tr>
<tr>
<td>96</td>
<td>11</td>
<td>6.1±0.4</td>
<td>1.57±0.11</td>
<td>nt</td>
<td>19.7 (15.4-24.5)</td>
<td>nt</td>
</tr>
<tr>
<td>144</td>
<td>0</td>
<td>4.7±02</td>
<td>1.59±0.07</td>
<td>95.6 (94.4-96.8)</td>
<td>4.4 (2.6-6.1)</td>
<td>31.2 (25.7-39.4)</td>
</tr>
<tr>
<td>144</td>
<td>11</td>
<td>6.1±0.2</td>
<td>1.71±0.01</td>
<td>nt</td>
<td>51.0 (36.1-57.0)</td>
<td>nt</td>
</tr>
</tbody>
</table>

In general, the bioassays highlighted a decrease in soil ecotoxicity with the presence of lime and DWTR (144 t DM ha\(^{-1}\)).

Figure. Growth rate (d\(^{-1}\)) from the microalgae P. subcapitata after 3 days exposed to the treatments with different doses of DWTR, with and without lime (mean ± SD; n= 6; *p <0.05, Dunnett's test with a control (MBL).
7.3. Experiments with DWTR

CONCLUSIONS

The amendments improved soil characteristics (pH, OM, N and K content), decreased metal extractability / bioavailability (especially for Cu and Zn), and allowed plant growth, which was impossible in the non-amended soil.

Better results could be achieved with a mineral fertilization with P and K.

It is possible to recommend the application of 96 or 144 t DWTR ha\(^{-1}\), with the simultaneous application of lime (11 t CaCO\(_3\) ha\(^{-1}\)), which allowed a plant cover with *Agrostis tenuis*.

Pb concentration in the shoots were lower than the typical values of contaminated plants, but the same was not true for Cu and Zn with the higher application rate → a different plant should be tested or the application rate lowered.

**Soil-water extract ecotoxicity decreased**, as a consequence od DTWR + lime application.

However, DWTR were unable to increase soil microbial activity, evaluated by dehydrogenase activity, and by other exoenzymes activities.

(Alvarenga et al., 2018)
WASTES FROM THE PULP AND PAPER INDUSTRY

European Waste Framework Directive (2008/98/EC) … waste disposal at a landfill should be the last option to be taken…

Moreover, the European Union (EU) have identified several key targets to achieve a sustainable growth… (European Commission, 2010).

Key targets to attain a sustainable growth at the climate change and energy level were defined:
• 20% reduction in greenhouse gas emissions (lower than 1990 levels),
• 20% increase in energy efficiency, and
• 20% of energy coming from renewable sources, by 2020.

This policies will lead to an increment in the combustion of biomass in the EU area in a near future, with a concomitant increase in the production of biomass ashes, which landfill disposal should be avoided.
7.4. Wastes from the pulp and paper industry

A research was funded by the Life Program:

Life No_Waste - LIFE14 ENV/PT/000369- “Management of biomass ash and organic waste in the recovery of degraded soils: a pilot project set in Portugal”.

(Alvarenga et al., submitted)
Wastes produced in the pulp and paper industry, have an interesting composition to be used in the remediation of acid soils, alternative to their landfill disposal.

Biomass ash (from the combustion of forest residues) can be used for fertilization, correcting some nutrient deficiencies (K, P, Mg and Ca).

They are alkaline (pH 9-13), which can improve the buffering capacity of acid soils.

But, biomass ashes are insufficient to provide OM and N, so, their combination with biological sludges (cellulosic sludges), from the wastewater treatment plant at the paper mill, can overcome that deficiency.
The co-granulation of biomass ash with biological sludges, can produce a material easier to transport and to apply (especially for fly ashes).

2. OBJECTIVES

- To evaluate the use of biomass ash and biological sludge, in different mixture formulations, to improve the quality of soils affected by mining activities (Aljustrel mine, Iberian Pyrite Belt).
- To evaluate the need to apply mixed municipal solid waste compost (MSWC), to overcome the OM and N deficiency.
- The experiments comprised an incubation experiment, to allow the selection of the application doses, and a pot experiments, with Agrostis tenuis Sibth, to evaluate the possibility of establishing a plant cover in the amended soils.

(Alvarenga et al., submitted)
7.4. Wastes from the pulp and paper industry

Soil from the Aljustrel mine (Iberian Pyrite Belt)

- Very acid: pH 3.05,
- High electrical conductivity: EC 3.65 mS cm⁻¹,
- Low OM content: 0.6%,
- High potentially toxic trace elements content:
  → 1490 mg Cu kg⁻¹
  → 1195 mg Pb kg⁻¹
  → 800 mg Zn kg⁻¹

(Alvarenga et al., submitted)
7.4. Wastes from the pulp and paper industry

Previous incubation assay:

allowed the selection of two different types of granules, and their application rates:

- **10S90A**: 10% cellulosic sludge + 90% biomass ash, and
- **30S70A**: 30% cellulosic sludge + 70% biomass ash.
- Indicated the need to apply **mineral fertilization** with N and P.
- Suggested the evaluation of the simultaneous application of the equivalent to 50 t ha\(^{-1}\) of compost (MMSWC).

Pot experiment:

- Pots with 1 kg of soil (4 replicates per treatment),
  - **Application rates 2.5, 5 and 10% (w/w)**, of both granules,
  - Non-amended soil (S) and soil with mineral fertilization (SF) were used as controls.
  - Soil + amendments were watered to 60% WHC in one day, and roughly mixed in the next day.
  - After an incubation period of 20 d, pots were sown with *Agrostis tenuis*,
  - All pots, except the control, received a basal dressing of N and P.
  - Two months after growing, outdoors, occasionally watered, soils and plants were analyzed.

(Alvarenga et al., submitted)
7.4. Wastes from the pulp and paper industry

Results were assessed evaluating:

- **Soil characteristics:** pH(H₂O), EC, OM, N\textsubscript{Kjeldahl}, extractable P and K.

- **Total and leachable trace elements in soils:** aqua-regia digestion and the soil water-extract (1:10 w/v), obtained with the DIN 38414-S4 (1984).

- **Soil enzymatic activities:** dehydrogenase, β-glucosidase, acid-phosphatase, cellulase, and protease activities.

- **The capacity to establish a plant cover with Agrostis tenuis.**

- **Soil ecotoxicological bioassays with the soil-water extracts:** (i) luminescence inhibition of Vibrio fischeri; (ii) 24-h mortality test with Thamnocephalus platyurus; and (iii) 72-hours population growth of the green microalgae Pseudokirchneriella subcapitata.

(Alvarenga et al., submitted)
7.4. Wastes from the pulp and paper industry

Effects on soil chemical characteristics

- Significant increase in soil pH, to values between 6-7.
- Increase in soil salinity was small, but more marked with compost.
- Compost application was essential to increase soil organic matter, N and P content.

<table>
<thead>
<tr>
<th>Variation</th>
<th>pH</th>
<th>EC</th>
<th>OM (%)</th>
<th>N KJ (%)</th>
<th>P extractable</th>
<th>K extractable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td><img src="image" alt="Control pH" /></td>
<td><img src="image" alt="Control EC" /></td>
<td><img src="image" alt="Control OM" /></td>
<td><img src="image" alt="Control N KJ" /></td>
<td><img src="image" alt="Control P" /></td>
<td><img src="image" alt="Control K" /></td>
</tr>
<tr>
<td>Treatment1</td>
<td><img src="image" alt="Treatment1 pH" /></td>
<td><img src="image" alt="Treatment1 EC" /></td>
<td><img src="image" alt="Treatment1 OM" /></td>
<td><img src="image" alt="Treatment1 N KJ" /></td>
<td><img src="image" alt="Treatment1 P" /></td>
<td><img src="image" alt="Treatment1 K" /></td>
</tr>
<tr>
<td>Treatment2</td>
<td><img src="image" alt="Treatment2 pH" /></td>
<td><img src="image" alt="Treatment2 EC" /></td>
<td><img src="image" alt="Treatment2 OM" /></td>
<td><img src="image" alt="Treatment2 N KJ" /></td>
<td><img src="image" alt="Treatment2 P" /></td>
<td><img src="image" alt="Treatment2 K" /></td>
</tr>
</tbody>
</table>

(Alvarenga et al., submitted)
7.4. Wastes from the pulp and paper industry

Effects on soil enzymatic activities

Dehydrogenase activity increased, an overall indicator of microbial activity, and the activity of both enzymes from the C-cycle, β-glucosidase and cellulases (very active because of C-content of the cellulosic sludges.

(Alvarenga et al., submitted)
7.4. Wastes from the pulp and paper industry

Effects on soil-water extract chemical properties and trace elements leachability

Extractable Pb, Cr, Cd and Ni were very low, below the limits of detection of the technique:

\[ \text{LD(Pb)} = 0.17 \text{ mg/L}; \quad \text{LD(Cr)} = 0.17 \text{ mg/L}; \quad \text{LD(Cd)} = 0.01 \text{ mg/L}; \quad \text{LD(Ni)} = 0.03 \text{ mg/L}. \]
7.4. Wastes from the pulp and paper industry

Effects on soil-water extract ecotoxicity

**Figure.** Effects of the treatments on soil-water extract toxicity towards *P. subcapitata* (% growth inhibition) (mean ± standard deviation, n=3).

- In general, soil-water extract toxicity decreased.
- Compost beneficial effect on the soil-water extract toxicity was not evident.

<table>
<thead>
<tr>
<th>Type of material</th>
<th>Application dose (% w/w)</th>
<th>MSWC (t ha⁻¹ dw)</th>
<th>V. fischeri 30 min-EC₅₀</th>
<th>T. platyurus 24h-EC₅₀</th>
<th>D. magna 48h-EC₅₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>0</td>
<td>0</td>
<td>nt</td>
<td>35.1 (31.2-39.7)</td>
<td>27.9 (23.2-36.9)</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>50</td>
<td>nt</td>
<td>54.1 (47.1-63.9)</td>
<td>44.5 (37.8-53.7)</td>
</tr>
<tr>
<td>SF</td>
<td>0</td>
<td>0</td>
<td>53.9 (53.4-54.1)</td>
<td>nt</td>
<td>nt</td>
</tr>
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<td>76.1 (75.9-76.2)</td>
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<td>nt</td>
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<td></td>
<td>2.5</td>
<td>50</td>
<td>nt</td>
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<td></td>
<td>5</td>
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<td>nt</td>
<td>nt</td>
<td>nt</td>
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<tr>
<td></td>
<td>10</td>
<td>0</td>
<td>nt</td>
<td>95.0 (79.9-120.4)</td>
<td>75.1 (62.8-88.0)</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>50</td>
<td>nt</td>
<td>97.8 (82.3-124.2)</td>
<td>nt</td>
</tr>
<tr>
<td>30S70A</td>
<td>2.5</td>
<td>0</td>
<td>nt</td>
<td>nt</td>
<td>nt</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>50</td>
<td>nt</td>
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<tr>
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<td>10</td>
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<td>nt</td>
<td>nt</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>50</td>
<td>nt</td>
<td>nt</td>
<td>nt</td>
</tr>
</tbody>
</table>

*Table.* Effects of the treatments on soil-water extract toxicity towards different organisms (mean ± standard deviation, n=3).

(Alvarenga et al., submitted)
Contrary to non-amended control pots, it was possible to establish a plant cover with *A. tenuis* in pots where correctives were applied.

However, after some time, necrosis of leaf margins and tips occurred, typically in older leaves first.

**Phytotoxicity** was first attributed to a possible increase in soil salinity, since it was possible to observe some salt deposition after water evaporation. However…

(Alvarenga et al., submitted)
Secondary salinity was high, but did not increase with the amendments, but…

Some ions which can promote specific toxicity, like chloride and sodium, increased markedly after amendments application.

Soil-water extract chloride (Cl\(^-\))

Maximum recommended value for irrigation water

Soil-water extract sodium (Na\(^+\))
CONCLUSIONS

- It is possible to amend these soils with mixtures of biomass ash + biological sludge, but with the simultaneous application of mineral fertilization and compost, in order to fully overcome the deficiencies in OM, as well as in available N and P.

- It was possible to reduce the potentially toxic trace elements mobility in soil, and to correct its acidity.

- It was possible to improve soils quality, as evaluated by soils enzymatic activities, and to reduce the toxic response towards some aquatic organisms (the soils retention function was improved).

- The amendments were not sufficient to establish a plant cover in the long term.

- Further research is needed, to evaluate different granular formulations, or the previous conditioning of the soil or waste materials, to reduce soluble-salt content, and sodium and chloride ions (e.g., ageing of the granules, washing of the compost, or of the biomass ashes).

(Alvarenga et al., submitted)
WASTES FROM THE PULP AND PAPER INDUSTRY

Waste-based materials preparation:

**BAG**: Biomass ash granules, stabilized for about 6 months, outdoors (*).

**Comp**: Composted biological sludge (cellulosic sludge from the secondary treatment), subjected to 6 months of composting, outdoors (*).

**BA + BS**: A mixture of biomass ash (BS) and biological sludge (BS), without any stabilization procedure.

(*) The previous conditioning of the waste materials allowed a reduction in soluble-salt content, sodium and chloride ions, and the stabilization of the biological sludge.
7.5. Moving to the field…

Field plots preparation at São Domingos mine area (10 m x 10 m per plot):
7.5. Moving to the field...

Field plots preparation at São Domingos mine area (10 m x 10 m per plot):

March 2018: Construction of the test plots by EDM
7.5. Moving to the field…

FIELD PLOTS SET-UP (May 2018):

**Control:** ≈ 40 m³ soil/plot, from each mining area, without amendments.

**BAG:** Biomass ash granules, stabilized for about 6 months, outdoors ≈ 2.4 t dw
BAG/plot - application rate ≈ 5% dw

**BAG + Comp:** ash granules (≈ 2.4 t dw
BAG/plot - Application rate ≈ 5% dw) + Composted biological sludge (1 t dw compost/plot - application rate ≈ 2.5% dw)

**BA + BS:** A mixture of biomass ash (BS) and biological sludge (BS), without any stabilization procedure (≈ 3 t dw mixture/plot - Application rate ≈ 3% dw BA+ 2.5% dw BS)

<table>
<thead>
<tr>
<th></th>
<th>Aljustrel</th>
<th>Lousal</th>
<th>São Domingos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td>Control</td>
</tr>
<tr>
<td>BAG</td>
<td></td>
<td></td>
<td>BAG</td>
</tr>
<tr>
<td>BAG + Comp</td>
<td></td>
<td></td>
<td>BAG + Comp</td>
</tr>
<tr>
<td>BA + BS</td>
<td></td>
<td></td>
<td>BA + BS</td>
</tr>
</tbody>
</table>
7.5. Moving to the field…

Mixing the amendments to be tested…
7.5. Moving to the field...

Watering the plots...

Aljustrel (control): upon irrigation

Lousal (control): upon irrigation

S. Domingos (control): upon irrigation
7.5. Moving to the field…

October 2018: half of each plot will be sown with a mixture of seeds of plants (some autochthonal, with resistance to drought conditions, some with the capacity to make associations with rhizobium, to fix nitrogen...).

18 month: monitoring

<table>
<thead>
<tr>
<th>Sowing:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>33,23% Loliurn</td>
<td></td>
</tr>
<tr>
<td>Medicago nigra (Luzerna)</td>
<td></td>
</tr>
<tr>
<td>8,31% Echium plantagineum (Soagem)</td>
<td></td>
</tr>
<tr>
<td>Raphanus raphanistrum (Saramago)</td>
<td></td>
</tr>
<tr>
<td>Crysanthemum segetum (Pimpilho)</td>
<td></td>
</tr>
<tr>
<td>3,88% Dactilis glomerata</td>
<td></td>
</tr>
<tr>
<td>4,15% Trifolium subterraneum</td>
<td></td>
</tr>
<tr>
<td>4,15% Vica villosa</td>
<td></td>
</tr>
<tr>
<td>26,31% Triticale var. curtido</td>
<td></td>
</tr>
<tr>
<td>13,85% Aveia var edxidna</td>
<td></td>
</tr>
<tr>
<td>6,12% Tremocilha</td>
<td></td>
</tr>
<tr>
<td>100,00%</td>
<td></td>
</tr>
</tbody>
</table>

Physical, chemical, biochemical, microbiological, ecotoxicological parameters (soil, pore water, plants)

Changes in soil properties
Establishment of plant cover
Recovery of soil functions
7.5. Moving to the field…

Preliminary results (September 2018): spontaneous vegetation in some plots.
7.5. Moving to the field...

Preliminary results (September 2018):

- **pH**
- **EC (mS/cm)**
- **OM (%)**
- **N Kjeldahl (%)**
7.5. Moving to the field…

Preliminary results (September 2018):

- $P_{\text{extractable}}$ (mg P$_2$O$_5$/kg dm)
- $K_{\text{extractable}}$ (mg K$_2$O/kg dm)
- DHA activity (mg TPF/g dm/16h)
8. CONCLUDING REMARKS

- Gentle remediation technologies, like assisted-phytoremediation, are the best options to the remediation of large areas, contaminated with trace elements, like abandoned mines;
- The use of organic and inorganic amendments are essential, and wastes should be considered as amendments;
- The risks and benefits of their use should be evaluated considering an holistic perspective: improvement in soil functionality and productivity;
- Composting is the best option to deliver a stabilized organic waste-derived amendments to soil, diminishing toxic effects;
- MMSWC: good balance of nutrients and OM content, acidity correction, but high trace metals concentration;
- GWC: low trace metals concentration, but with low performance in acidity correction and on OM and nutrients supplementation;
- Sewage sludges have pronounced short-term beneficial effects on plant productivity and microbial activity, but their lack of maturation can induce some toxic effects;
- Drinking-water treatment residuals: a possibility, if mineral nutrients and liming materials are also added, but the soil microbial activity remains low.
- Wastes from the pulp and paper industry: soluble salts, chloride and sodium are a concern in biomass ash… cellulosic sludges should be also stabilized (e.g. composted).
8. CONCLUDING REMARKS

Overview of countries that have soil contamination inventory

In Portugal we don’t have:
- Soil quality legislation;
- Systematic preliminary survey;
- Main site investigations;
- Remediation measures;
- Mining sites are being rehabilitated only with constructive techniques (dig, dump, cover, control acid mine drainage…);
- … long way ahead…

No data for Portugal.

9. REFERENCES


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Thank you!

palvarenga@isa.ulisboa.pt

Juan Vilela Lozano:
CEA GREEN LAB Coordinator
Centro de Estudios Ambientales