Soil, plant and red mud: Case study of two deposits in Provence

– DORIS Project –

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Research objectives

How these bauxite residues interact with terrestrial ecosystems through the soil-plant continuum?

The researches undertaken were aimed:

- To study the effects of bauxite residues on the biogeochemical characteristics of soils
- To explore how and to what extent these tailings modulated the structuring and functional responses of pedobiological components
- To determine the impacts on the functioning of these pedosystems
- To consider valuation solutions and to recommend management actions of past, current, and forthcoming deposits

Study sites

Terrestrial deposits

Mange-Garri, Bour-Bel-Air

Pond #4

Griffon, Vitrolles

Slag-heap
Study stations

Pond #4, Mange Garri

Elevation profile

Z1
Z2
Z3

Slag heap, Griffon

Z1
Z2
Z3

Elevation profile

0.06 0.11 0.17 0.23 0.29 0.34 0.4 0.46 0.53 0.6

130 140 150 160 170 180 190 200 210 220

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<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Mean ± SD (min - max)</th>
<th>Variable</th>
<th>Unit</th>
<th>Mean ± SD (min - max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>ppm MS</td>
<td>31904 ± 8036 (15369 - 42555)</td>
<td>NH$_4^+$</td>
<td>g/kg MS</td>
<td>4 ± 4 (0 - 14)</td>
</tr>
<tr>
<td>Mg</td>
<td>ppm MS</td>
<td>3921 ± 1222 (676 - 5709)</td>
<td>P$_{Olsen}$</td>
<td>ppm MS</td>
<td>44 ± 50 (10 - 174)</td>
</tr>
<tr>
<td>Al</td>
<td>ppm MS</td>
<td>52945 ± 3395 (43739 - 57458)</td>
<td>Na$_{bioavailable}$</td>
<td>ppm MS</td>
<td>1494 ± 538 (368 - 2568)</td>
</tr>
<tr>
<td>Si</td>
<td>ppm MS</td>
<td>47410 ± 15450 (7711 - 63677)</td>
<td>Mg$_{bioavailable}$</td>
<td>ppm MS</td>
<td>54 ± 39 (16 - 138)</td>
</tr>
<tr>
<td>P</td>
<td>ppm MS</td>
<td>892 ± 483 (311 - 2136)</td>
<td>Cu$_{bioavailable}$</td>
<td>g/kg MS</td>
<td>1.1 ± 0.8 (0.4 - 3.7)</td>
</tr>
<tr>
<td>S</td>
<td>ppm MS</td>
<td>150 ± 185 (0 - 475)</td>
<td>Th$_{bioavailable}$</td>
<td>g/kg MS</td>
<td>0.1 ± 0.0 (0.0 - 0.2)</td>
</tr>
<tr>
<td>K</td>
<td>ppm MS</td>
<td>2984 ± 873 (262 - 4594)</td>
<td>Clay</td>
<td>ppm MS</td>
<td>253 ± 53 (115 - 336)</td>
</tr>
<tr>
<td>Ca</td>
<td>ppm MS</td>
<td>44957 ± 22609 (3726 - 93054)</td>
<td>Fine silt</td>
<td>ppm MS</td>
<td>296 ± 84 (174 - 450)</td>
</tr>
<tr>
<td>Ti</td>
<td>ppm MS</td>
<td>17273 ± 5801 (4681 - 37352)</td>
<td>Coarse silt</td>
<td>g/kg MS</td>
<td>131 ± 35 (68 - 199)</td>
</tr>
<tr>
<td>V</td>
<td>ppm MS</td>
<td>691 ± 289 (497 - 1989)</td>
<td>Fine sand</td>
<td>g/kg MS</td>
<td>166 ± 50 (104 - 292)</td>
</tr>
<tr>
<td>Cr</td>
<td>ppm MS</td>
<td>723 ± 358 (418 - 2321)</td>
<td>Coarse sand</td>
<td>g/kg MS</td>
<td>154 ± 98 (31 - 382)</td>
</tr>
<tr>
<td>Mn</td>
<td>ppm MS</td>
<td>621 ± 100 (431 - 860)</td>
<td>Carbonates</td>
<td>g/kg MS</td>
<td>165 ± 59 (97 - 273)</td>
</tr>
<tr>
<td>Fe</td>
<td>ppm MS</td>
<td>151948 ± 22988 (128744 - 239480)</td>
<td>DBD</td>
<td>g MS/mL</td>
<td>2.4 ± 0.2 (1.9 - 2.8)</td>
</tr>
<tr>
<td>Ni</td>
<td>ppm MS</td>
<td>205 ± 53 (18 - 258)</td>
<td>WHC$_{pF3}$</td>
<td>%</td>
<td>28 ± 2 (21 - 32)</td>
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<tr>
<td>Cu</td>
<td>ppm MS</td>
<td>29 ± 15 (18 - 76)</td>
<td>CEC$_{Metson}$</td>
<td>cmol+/kg MS</td>
<td>15.0 ± 2.2 (10.5 - 20.8)</td>
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<tr>
<td>Zn</td>
<td>ppm MS</td>
<td>124 ± 93 (36 - 291)</td>
<td>pH$_{water}$</td>
<td>Unit(1/20)</td>
<td>10.1 ± 0.3 (9.3 - 10.4)</td>
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<tr>
<td>As</td>
<td>ppm MS</td>
<td>40 ± 15 (21 - 80)</td>
<td>Eh</td>
<td>mV$_{1/20}$</td>
<td>333 ± 11 (316 - 367)</td>
</tr>
<tr>
<td>Cd</td>
<td>ppm MS</td>
<td>0.1 ± 0.0 (0.0 - 0.2)</td>
<td>EC</td>
<td>µS/cm$_{1/20}$</td>
<td>239 ± 75 (99 - 347)</td>
</tr>
<tr>
<td>Pb</td>
<td>ppm MS</td>
<td>113 ± 35 (56 - 181)</td>
<td>TOC</td>
<td>g/kg MS</td>
<td>15.5 ± 11.4 (5.5 - 45.4)</td>
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<tr>
<td>Th</td>
<td>ppm MS</td>
<td>77 ± 14 (48 - 101)</td>
<td>TN</td>
<td>g/kg MS</td>
<td>1.3 ± 1.1 (0.4 - 3.9)</td>
</tr>
<tr>
<td>U</td>
<td>ppm MS</td>
<td>13 ± 2 (10 - 16)</td>
<td>C:N</td>
<td>Molar</td>
<td>15.8 ± 3.1 (11.5 - 21.2)</td>
</tr>
</tbody>
</table>

Mean ± SD (min - max)
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Vegetation

$R^2_{adj} = 0.403^{***}$

79 species

Variables tested
- Bact NMDS1 + 2
- Fung NMDS1 + 2
- Mic PC1
- BGC D1 + 2 + 3
Vegetation

Concordance analysis

- Assoc 1 (21 sp)
- Assoc 2 (17 sp)
- Assoc 3 (21 sp)
- Assoc 4 (13 sp)
- Assoc 5 (5 sp)

PC1 (12.84%)

RDA2 (32.66%)

Z1_1

Z1_2

Z1_3

Z1_4

Z2_1

Z2_2

Z2_3

Z2_4

Z2_5

Z3_1

Z3_2

Z3_3

Z3_4

Z3_5

Mic PC1

BGC D1

A_1

A_2

A_3

A_4

A_5

B_1

B_2

B_3

B_4

B_5

Assoc 1 (21 sp)

Assoc 2 (17 sp)

Assoc 3 (21 sp)

Assoc 4 (13 sp)

Assoc 5 (5 sp)
Microorganisms

**Variables tested**
- Veg NMDS1 + 2
- Veg cover
- Litter
- Bare ground
- BGC D1 + 2 + 3

**Bacteria**

42 OTUs
Variables tested
- Veg NMDS1 + 2
- Veg cover
- Litter
- Bare ground
- BGC D1 + 2 + 3
Variables tested
- Bact NMDS1 + 2
- Fung NMDS1 + 2
- Veg NMDS1 + 2
- Veg cover
- Litter
- Bare ground
- BGC D1 + 2 + 3
**Microbial functions**

### Multivariate Regression Tree analysis

**TOC < 10.55 | TOC ≥ 10.55**

- **48.35 %**

**TOC < 10.55**

- **59.78 %**

  - **Error**: 0.40
  - **CV Error**: 0.63
  - **SE**: 0.08

**Alternative predictor variables**

- **TN < 1.03 | TN ≥ 1.03**
  - **48.20 %**
- **\( P_{Olsen} < 31.5 \mid P_{Olsen} ≥ 31.5 \)**
  - **47.08 %**
- **EC ≥ 250.5 | EC < 250.5**
  - **46.71 %**
- **Mg\_bio < 43.8 | Mg\_bio ≥ 43.8**
  - **46.71 %**

**TOC ≥ 10.55**

- **48.35 %**

**EC ≥ 140.4 | EC < 140.4**

- **11.44 %**

**A, B, Z3₁-3.5**

- **n = 14**

**Z2, Z3₄**

- **n = 6**

**Z1**

- **n = 4**

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Conclusions

How these bauxite residues interact with terrestrial ecosystems through the soil-plant continuum?

What this work showed at the scale of the deposits studied:

- Existence of two inverted gradients: pH, EC, Na versus SOM, nutrients
- Structuring of fungal and vegetal communities and microbial functions along these gradients
- Increasing alkalinity and sodicity inhibited the biological processes of pedogenesis and, by feedback, slowed the OM enrichment of soils
- Evidence of strong above-belowground linkages through reciprocal functional relationships
- Identification of indicator plant species of alkaline sodic habitats/soils similar to those of the Mediterranean coastline (e.g. sansouire)

Outlooks

REDMUD Project – Red mud inputs into soils: responses and structuring of microbial and plant communities

- To optimize the red mud soil matrix to establish sustainable favorable soil conditions
- To favor the revegetation and progressive Na decrease of red mud soils through the use of halophyte/halophile plant species evidenced

MARS Project – Microbial diversity Assessment in Redmud Soils

- To explore the diversity and structure of bacterial and fungal communities of red mud soils (metabarcoding)
- Screening and selection of useful microbial strains