Biochar substrates for degradation of organic pollutants in soils of former military areas

LaTerra

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*Freie Universität Berlin, #Research Institute for Post Mining Landscapes
### Status of Inventory: Suspected Contaminated Sites in Germany

<table>
<thead>
<tr>
<th>Federal State</th>
<th>information stand</th>
<th>Abandoned Waste Disposal Sites</th>
<th>Abandoned Industrial Sites</th>
<th>Sites in all</th>
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<tbody>
<tr>
<td>Baden-Württemberg</td>
<td>2010</td>
<td>3253</td>
<td>7.766</td>
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<td>Bavaria</td>
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<td>10.193</td>
<td>3.737</td>
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<td>Bremen</td>
<td>2011</td>
<td>55</td>
<td>2.910</td>
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<td>Hamburg</td>
<td>2011</td>
<td>420</td>
<td>1.933</td>
<td>1.815</td>
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<tr>
<td>Hessen</td>
<td>2011</td>
<td>316</td>
<td>350</td>
<td>1040</td>
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<tr>
<td>Mecklenburg-Western Pomeria</td>
<td>2010</td>
<td>4.113</td>
<td>7.231</td>
<td>5.835</td>
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<td>Lower Saxony</td>
<td>2011</td>
<td>8.976</td>
<td>30.900</td>
<td>93.825</td>
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<td>North Rhine Westphalia</td>
<td>2010</td>
<td>18.337</td>
<td>24.642</td>
<td>75.370</td>
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<tr>
<td>Rhineland-Palatinate</td>
<td>2011</td>
<td>10.578</td>
<td>n.d.</td>
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<td>Saarland</td>
<td>2010</td>
<td>1.801</td>
<td>2.442</td>
<td>1.977</td>
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<td>7.655</td>
<td>22.418</td>
<td>19.785</td>
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<td>Saxony-Anhalt</td>
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<td>5.985</td>
<td>13.958</td>
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<tr>
<td>Schleswig-Holstein</td>
<td>2010</td>
<td>2.412</td>
<td>16.096</td>
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<tr>
<td>Thuringia</td>
<td>2011</td>
<td>5.556</td>
<td>11.094</td>
<td>12.570</td>
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<tr>
<td><strong>Germany</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>appr. 315.000</strong></td>
</tr>
</tbody>
</table>

*Note: n.d. indicates not determined.*
Situation in the Federal State of BRANDENBURG

Federal Country of Brandenburg:

- 1989 military occupied area (WGT, NVA):
  - 230,000 ha (8% of the whole country of Brandenburg)
- 200,000 ha without further military use

Sandy soils with low organic matter

PAH  MHC
What´s the problem?

Large contaminated areas with high costs for remediation

Competition for area between food crops and energy crops
Project goals

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Degradation of organic pollutants

Enhancement of soil fertility

Restoration of ecologic and economic potential of contaminated sites and degraded areas

via application of biochar substrates

on the basis of regional using of biogenic wastes and renewable raw materials

Renewable raw materials

Climate gas reduction CO$_2$-storage

Closing of regional cycles

Dr. agr. Ines Vogel – US Biochar 2012
Research for climate and sustainability

Degradation of organic pollutants

Reforestations of large scale windbreakage areas

Renaturation of post-mining-landscapes

Project partner and project structure

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Project coordination (FUB)
project coordination quality assurance, actor management, public relation activities

Cross-sectional project (HL)
energy and material flow management, value-creation network

Regional projekt 1 (FUB)
„military conversion areas“
Brandenburg, county Teltow Fläming

Regional projekt 2 (FIB)
„post mining landscapes“
Brandenburg, counties Oberspreewald-Lusatia, Elbe-Elster

Regional projekt 3 (Fh-IME)
„forest management“
North Rhine-Westphalia, city of Schmallenberg

Terra Preta production
Areal GmbH subcontractor

Dr. agr. Ines Vogel – US Biochar 2012
Selection of testing area

Tank repair area and gasstation

Dr. agr. Ines Vogel – US Biochar 2012
Selection of testing area

Further industrial used area – former tarboard-factory
Examination programme

- Physical, physico-chemical and chemical examinations for characterising soils and substrates
- Leaching tests concerning mineral and organic contaminants
- Biological examinations (respiration, nitrification, earthworm, seedling emergence)

**Contaminated sites (MHC, PAH)**

- **Pot trials**
  - 2011 - 2014

- **Lysimeter trials**
  - 2012 - 2014

- **Outdoor tests**
  - 2012 - 2014
Pot trials - parameter soil/biochar substrates

- Analysis of soil and the beginning and end of vegetation period

- PAH, MHC
- water content, pH, conductivity, CEC
- C_t, N_t, S_t, N_min, KAK_{pot}, P_{avail}, K_{avail}, Mg_{avail}, C_{org}
- Ca, Mg, K, P, Mn, Cu, Zn, Ni, Cr, Pb, Cd, Hg, As, Tl
- Leaching - columns- und shaking - trials

Biological soil parameters:
- Biomass
- Soil respiration
- Nitrification
Contamination levels

<table>
<thead>
<tr>
<th>MHC-soil content</th>
<th>PAH-soil content</th>
</tr>
</thead>
<tbody>
<tr>
<td>5900 mg/kg</td>
<td>90 mg/kg</td>
</tr>
<tr>
<td>0.7 mg/kg</td>
<td>277 mg/kg</td>
</tr>
</tbody>
</table>

Very high available content of MHC (89 ... 95 %)

The highest amounts of PAH contamination, in the pure PAH-soil are fluoranthen (16 %), pyren (15 %), benzo(a)pyren (10,1 %)
Design of pot trials in 2011

MHC, PAH contaminated and non-contaminated soils

**With plant**
- 2.8 M.-% substrate
  - with 15 Vol.% BC (A3)
  - with 30 Vol.% BC (B3)
- 14 M.-% substrate
  - with 15 Vol.% BC (A3)
  - with 30 Vol.% BC (B3)

**Biochar addition**

**Amount according to a biochar compostion like 30 Vol.% - 14 M.-% substrate**

**Without plant**
- 14 M.-% substrate
  - with 15 Vol.% BC (A3)
  - with 30 Vol.% BC (B3)

**Biochar-substrates additions**
Production of biochar substrates

Feedstock:
- grass, lop
- biochar (pyrolysis, 15 u. 30 vol.-%)
- + digestate (5 % D.M.; 300 l m⁻³)
- + basalt powder (15 kg m⁻³)

<table>
<thead>
<tr>
<th>TPS-variant</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>C_{org}</th>
<th>C/N</th>
<th>pH</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M.-%</td>
<td>M.-%</td>
<td>M.-%</td>
<td>M.-%</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>TPS Q1</td>
<td>1.28</td>
<td>0.25</td>
<td>1.0</td>
<td>29</td>
<td>23</td>
<td>7.5</td>
<td>26</td>
<td>146</td>
</tr>
<tr>
<td>15 Vol.-% biochar</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>TPS Q2</td>
<td>1.14</td>
<td>0.17</td>
<td>0.8</td>
<td>39</td>
<td>34</td>
<td>7.5</td>
<td>19</td>
<td>124</td>
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<tr>
<td>30 Vol.-% biochar</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Biological substrates characterisation / quality assurance

Cress test – phytotoxic gases
Aim: Detection of gaseous phytotoxic substances (Federal Compost Association)

At least 80% of the fresh matter of a reference substrate must be achieved:

LA-TP-A3 = 99.3 %
LA-TP-B3 = 83.8 %

⇒ Batches are free of phytotoxic compounds

Earthworm avoidance test
Aim: Examination of the effect on the fauna in terms of substrate preference (DIN ISO 17512-1: 2010-06)

Less than 20% of the total number of worms in Test-Substrate the Habitat function is restricted

GA2 F0% = 6.4
GA2 F15% = 3.6
GA2 IR0% = 6.6
GA2 IR15% = 3.4

⇒ Biochar-Substrate is not preferred

Pictures 4/5: cress test (Karin Friede)
Pictures 6/7: earthworm avoidance test (Karin Friede)
Effect of the addition of Biochar-Substrate to the potential nitrification in uncontaminated soil

The addition of Biochar-Substrate leads to an increase of the ammonium oxidation potential of the soil.

The activity of the ammonium oxidise bacteria increases with increasing substrate additions. A higher Biochar content in the substrate leads to a slight decrease in microbial activity of nitrifies.

Wet black soil (reference soil)
NO2-N=13,3 ng/g/min
(Dreher & Hund-Rinke 2001)

→ The addition of Biochar-Substrate leads to a decrease of apparent density
→ Better permeability of air
→ increase in microbial activity of nitrifies
Pot trial – soil carbon

Stable enrichment of soil carbon content

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Pot trial – Soil: pH (CaCl) in the MHC - variations

Already by very low biochar (< 1%) amendment huge effect on soil pH!
Pot trial – growth pattern of the maize plants – MHC contamination

growth pattern of the maize type *Subito* in MHC-contaminated soil

→ decrease of plant growth because of MHC – improvement with biochar substrates
Pot trial – growth pattern of the maize plants – PAH contamination

growth pattern of the maize plants *Subito* in PAH contaminated soil

→ no influence of aged PAH on plant growth
Higher growth with 30 Vol-% compared with 15 Vol-% Biochar content in the substrates.

Supplementary fertilizer N of the Biochar-Substrates was necessary because the added organic nitrogen was slowly released.

“Not activated Biochar” indicated no positive effects concerning to the growth pattern.

Inhibition of the growth pattern of plants in MHC-contaminated soil was significantly higher than the growth pattern of plants in PAH contaminated soil, the reason was the higher amount of available MHC.
Results of second vegetation period - PAH

In the biochar substrate variants:
- Higher fertilizer efficiency
- Far better growth
- No growth depression
Results of second vegetation period - MHC

In the biochar substrate variants:
- Higher fertilizer efficiency
- Far better growth
- No growth depression

- Control
- MHC
- MHC + 14(15) BCS
- MHC + 14(30) BCS
Pot trial – Reduction of the MHC-content

MHC concentrations (absolute value)

Reducing rate of MHC-Concentration

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Pot trial – Reduction of the PAH-content

PAH concentrations (absolute value)

Reducing rate of PAH-Concentration
Pot trial – Reducing rate of PAH/MHC content

Reducing rate of MHC-content
(absolutely value) with Biochar-Substrate-Mixture or Biochar-Mixture after the first vegetation period

Reducing rate of PAH-content
(absolutely value) with Biochar-Substrate-Mixture or Biochar-Mixture after the first vegetation period

→ lower reduction rates with plants - competition
Leaching tests

**Test overview**

**Batch test**
in progress
DIN 19527: 2012-08
DIN 19529: 2009-01

L/S ratio: 2:1 → static test
shaking time: 24h
centrifugation and filtration of the eluate

**Column test**
planned 2012/13
DIN 19528: 2009-01

L/S ratio: various (1:1; 2:1; 4:1 etc.)
→ dynamic test
inverse flow direction
(centrifugation and) filtration of the eluate

→ Determination of the leachable contaminants and nutrients of the soil/biochar substrates
Batch tests – first results

**PAH contaminations**

**PAH absolute value**

**PAH eluate concentration**

High reduction of PAH after 5 months

Increasing BC leads to decreasing eluate concentrations

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Batch tests – first results

PAH contaminations

PAH absolute value

leachable PAH contents regarding soil sample

increasing BC leads to decreasing leachable PAH contents
Batch tests – first results

**PAH contaminations**

**PAH absolute value**

**leachable PAH contents regarding soil total value**

Note: very low <0.1%!!!
Batch tests – first results

PAH contaminations – eluate parameter

**eluate parameter: pH value**

increasing BC leads to increasing pH value

**eluate parameter: Electric conductivity**

increasing BC leads to decreasing electric conductivity

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Batch tests – first results

### Leachable nutrients

<table>
<thead>
<tr>
<th></th>
<th>K</th>
<th>Mg</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 month</td>
<td>After 5 months</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PAH</strong></td>
<td>1.9</td>
<td>0.3</td>
<td>0.3</td>
<td>0.1</td>
<td>4.4</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>PAH + 10 Vol% Biochar substrate A3</strong></td>
<td>18</td>
<td>1.4</td>
<td>2.9</td>
<td>1.0</td>
<td>1.8</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>PAH + 10 Vol% Biochar substrate B3</strong></td>
<td>17</td>
<td>1.3</td>
<td>2.0</td>
<td>1.3</td>
<td>2.9</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>PAH + 50 Vol% Biochar substrate A3</strong></td>
<td>36</td>
<td>1.6</td>
<td>1.8</td>
<td>3.3</td>
<td>5.5</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>PAH + 50 Vol% Biochar substrate B3</strong></td>
<td>28</td>
<td>1.4</td>
<td>1.4</td>
<td>2.5</td>
<td>2.7</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>PAH + BC</strong></td>
<td>15</td>
<td>0.5</td>
<td>0.8</td>
<td>0.8</td>
<td>3.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>

After 5 months:

- **PAH** 25, 1.4, 2.6, 0.2, 3.6, 1.2
- **PAH + 10 Vol% Biochar substrate A3** 25, 1.4, 2.6, 0.2, 3.6, 1.2
- **PAH + 10 Vol% Biochar substrate B3** 15, 1.2, 2.0, 0.1, 2.6, 0.8
- **PAH + 50 Vol% Biochar substrate A3** 37, 1.9, 1.6, 0.8, 7.5, 1.2
- **PAH + 50 Vol% Biochar substrate B3** 22, 1.4, 1.3, 0.5, 4.5, 1.1

With increasing TPS dosage, the availability of nutrients increases, but not always with increasing BC content at the same dosage. After 5 months, in general, less leachable, but not generalizable. Potassium is very high leachable (up to 37% of the total content!)

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Batch tests – first results

**leachable nutrients**

- Elutionsverhalten von biokohlesubstratet sehr differenziert; Einfluss der Kohle erkennbar
- zum einen führen steigende BC-Gehalte zu sinkenden Eluatkonzentrationen, aber in Bezug zu den proz. Anteil vom Gesamtgehalt zeigt sich manchmal ein anderes Bild (vor/nach Gefäßversuch)
- PAK werden sehr gering eluiert (<0,1%), da gealterte PAK sehr schwer desorbierbar sind
- Nährstoffe/anorg. Elemente werden erwartungsgemäß leichter mobilisiert (Kalium!)
- laut Literatur können Schad-/nährstoffe an Kohlepartikel festgelegt werden, aber genauso gut mit feinen Partikeln ausgewaschen werden

- Batch test für Boden/TPS-Substrate gut durchführbar und liefert reproduzierbare und vergleichbare Ergebnisse
- interessant ist zudem die Elution von „reinen“ Biokohlesubstraten (TerraBoGa) → Methodenanpassung
Local project No. 2 – renaturation of post-mining-landscapes

In regional project 2 (Western Lusatia, county Oberspreewald-Lusatia) reclamation and renaturation of post-mining-landscapes is first priority. In this case, the project seeks for an upgrade of devastated soils for plant production as well as for restoration of soil functions and setup of organic soil substances.
Production of artificial Terra Preta Materials (TPS)

Feedstock:
- grass, lop
- biochar (pyrolysis, 15 u. 30 vol.-%)
- + digestate (5 % D.M.; 300 l m⁻³)
- + basalt powder (15 kg m⁻³)

<table>
<thead>
<tr>
<th>TPS-variant</th>
<th>N M.-%</th>
<th>P M.-%</th>
<th>K M.-%</th>
<th>C_{org} M.-%</th>
<th>C/N</th>
<th>pH</th>
<th>Cu mg 100g⁻¹</th>
<th>Zn mg 100g⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPS Q1 15 Vol.-% biochar</td>
<td>1.28</td>
<td>0.25</td>
<td>1.0</td>
<td>29</td>
<td>23</td>
<td>7.5</td>
<td>26</td>
<td>146</td>
</tr>
<tr>
<td>TPS Q2 30 Vol.-% biochar</td>
<td>1.14</td>
<td>0.17</td>
<td>0.8</td>
<td>39</td>
<td>34</td>
<td>7.5</td>
<td>19</td>
<td>124</td>
</tr>
</tbody>
</table>

limit BioAbfV (30 t): 70
300
Application of organic secondary raw materials for the reclamation of degraded sites

Michael Haubold-Rosar

C_{org}-contents in topsoils treated with Terra Preta Materials (TPS)

- dumped soil
- natural soil

Bar chart showing the comparison of C_{org}-contents in topsoils treated with different materials, including min. fert., 30 t TPS Q1, 60 t TPS Q1, 90 t TPS Q1, 30 t TPS Q1/a, 60 t TPS Q2, 15/10 t digestate, and 60 t compost.

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Dr. agr. Ines Vogel – US$Biochar 2012
Corn yields after application of biochar-substrates
Pot experiment: “Fertilizing capacity of biochar substrates”

Dry matter yields of *Dactylus glomerata* L. depending on $N_t$ - application on a dumped soil, first cut

\[
y = -7E-05x^2 + 0,0512x - 0,3047 \\
R^2 = 0,8715
\]

\[
y = -2E-06x^2 + 0,005x - 1,3163 \\
R^2 = 0,6556
\]

\[
y = -9E-07x^2 + 0,0023x - 0,3268 \\
R^2 = 0,6704
\]

$\Rightarrow$ Mineral N fertilizer equivalent $< 5\%$
Conclusions

• Reduction of organic pollution works
• Full effect development of biochar-substrates needs time, patience and a good feeling for all components and the local circumstances where the substrates are applied
• Design of substrates for special problems and conditions on site – guidance for transfer of results
Thank you very much for the attention!

Project foundation: Federal Ministry of Education and Research of Germany
Project period: 01.11.2010 – 31.10.2014

Part of working group Geoecology
## Substrates characterisation / quality assurance

### Compare of Biochar-Substrates batches – nutrients

<table>
<thead>
<tr>
<th>Biochar-Substrates</th>
<th>TP - LA - A3</th>
<th>TP - LA - A3</th>
<th>TP - LA - B3</th>
<th>TP - LA - B3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameter</strong></td>
<td>Small batch</td>
<td>Big batch</td>
<td>Small batch</td>
<td>Big batch</td>
</tr>
<tr>
<td>Dry matter [%]</td>
<td>50,8</td>
<td>45,2</td>
<td>52,5</td>
<td>46,9</td>
</tr>
<tr>
<td>pH (CaCl2)</td>
<td>8,1</td>
<td>7,5</td>
<td>7,4</td>
<td>7,6</td>
</tr>
<tr>
<td>Total carbon [%]</td>
<td>25,5</td>
<td>28,2</td>
<td>31,5</td>
<td>33,5</td>
</tr>
<tr>
<td>Total nitrogen [%]</td>
<td>1,2</td>
<td>1,2</td>
<td>1,2</td>
<td>1,0</td>
</tr>
<tr>
<td>Total phosphor [mg/kg dry matter]</td>
<td>2581</td>
<td>3435</td>
<td>2597</td>
<td>2388</td>
</tr>
<tr>
<td>Total potassium [mg/kg dry matter]</td>
<td>13865</td>
<td>13005</td>
<td>14200</td>
<td>9227</td>
</tr>
<tr>
<td>NO3-N [mg/l fresh matter]</td>
<td>11,1</td>
<td>1,2</td>
<td>31,5</td>
<td>1,2</td>
</tr>
<tr>
<td>NH4-N [mg/l fresh matter]</td>
<td>7,3</td>
<td>2,6</td>
<td>7,4</td>
<td>0,8</td>
</tr>
</tbody>
</table>

Table 1: Compare of Biochar-Substrate batches (own design)

→ the total of C, N, P, K between Small batch and Big batch is comparable
→ the soluble N in the Big batch is much lower then in the small batch → lack of nitrogen (maize)
## Pot trials - Soil- and Substrates characterisation

**Chem.-physic. Parameter of the Biochar-Substrates batches and the used soils**

<table>
<thead>
<tr>
<th>Biochar-Substrates/Soil Parameter</th>
<th>TP - LA - A3 total</th>
<th>TP - LA - B3 total</th>
<th>uncontaminated soil &lt; 2 mm</th>
<th>MHC &lt; 2 mm</th>
<th>PAH &lt; 2 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter [% fresh matter]</td>
<td>45,5</td>
<td>54,5</td>
<td>92,9</td>
<td>93,8</td>
<td>95,42</td>
</tr>
<tr>
<td>Water content [% fresh matter]</td>
<td>51,5</td>
<td>48,5</td>
<td>7,1</td>
<td>6,2</td>
<td>4,58</td>
</tr>
<tr>
<td>pH (CaCl2)</td>
<td>7,53</td>
<td>7,60</td>
<td>6,35</td>
<td>4,57</td>
<td>7,12</td>
</tr>
<tr>
<td>Salt content (fresh) [g/l]</td>
<td>3,50</td>
<td>1,94</td>
<td>0,3</td>
<td>0,02</td>
<td>0,28</td>
</tr>
<tr>
<td>Apparent density (fresh) [g/l]</td>
<td>772,8</td>
<td>688</td>
<td>1411,1</td>
<td>1553</td>
<td>1432,1</td>
</tr>
<tr>
<td>Apparent density (dry) [g/l]</td>
<td>355</td>
<td>329</td>
<td>1311</td>
<td>1457</td>
<td>1367</td>
</tr>
<tr>
<td>Maximum water holding capacity [Vol.-%]</td>
<td>71,8</td>
<td>77,5</td>
<td>39,4</td>
<td>41,3</td>
<td>39,5</td>
</tr>
<tr>
<td>Corg (loss of ignition) [% dry matter]</td>
<td>27,4</td>
<td>30,0</td>
<td>1,7</td>
<td>0,6</td>
<td>1,97</td>
</tr>
</tbody>
</table>

*Table 3: chem.-physic. Parameter of Biochar-Substrates batches and used soils (own design)*
Pot trials - Soil- and Substrates characterisation

NPP-contents of Biochar-Substrates batches and used soils

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Böden</th>
<th>TP - LA - A3 total</th>
<th>TP - LA - B3 total</th>
<th>uncontaminated soil &lt; 2 mm</th>
<th>MHC &lt; 2 mm</th>
<th>PAH &lt; 2 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total nitrogen [%]</td>
<td>1,2</td>
<td>1,0</td>
<td>0,07</td>
<td>0,04</td>
<td>0,08</td>
<td></td>
</tr>
<tr>
<td>Total phosphor [mg/kg dry matter]</td>
<td>3435</td>
<td>2387</td>
<td>347</td>
<td>529</td>
<td>369</td>
<td></td>
</tr>
<tr>
<td>Total potassium [mg/kg dry matter]</td>
<td>13005</td>
<td>9227</td>
<td>391</td>
<td>447</td>
<td>679</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: NPP-contents of Biochar-Substrate batches and soil (own design)

→ Nutrients content of uncontaminated and contaminated soils are comparable
→ Phosphorus and potassium increased in the Biochar-Substrate-A3, compared to B3
Substrates characterisation / quality assurance

Compare of Biochar-Substrates batches – inorganic & organic pollutant

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TP - LA - A3</th>
<th>TP - LA - A3</th>
<th>TP - LA - B3</th>
<th>TP - LA - B3</th>
<th>Bio waste Ordinance</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAH 16 [mg/kg dry matter]</td>
<td>0,15</td>
<td>0,65</td>
<td>0,10</td>
<td>0,75</td>
<td>30 t/ha</td>
</tr>
<tr>
<td>Cadmium [mg/kg dry matter]</td>
<td>0,33</td>
<td>&lt; 0,1</td>
<td>0,30</td>
<td>&lt; 0,1</td>
<td>1</td>
</tr>
<tr>
<td>Chromium [mg/kg dry matter]</td>
<td>39,0</td>
<td>42,7</td>
<td>38,7</td>
<td>34,2</td>
<td>70</td>
</tr>
<tr>
<td>Copper [mg/kg dry matter]</td>
<td>47,3</td>
<td>36,2</td>
<td>41,2</td>
<td>28,6</td>
<td>70</td>
</tr>
<tr>
<td>Nickel [mg/kg dry matter]</td>
<td>58,9</td>
<td>29,4</td>
<td>40,5</td>
<td>30,8</td>
<td>35</td>
</tr>
<tr>
<td>Plumb [mg/kg dry matter]</td>
<td>13,2</td>
<td>18,1</td>
<td>13,3</td>
<td>8,0</td>
<td>100</td>
</tr>
<tr>
<td>Zinc [mg/kg dry matter]</td>
<td>161,7</td>
<td>151,2</td>
<td>149,7</td>
<td>143,3</td>
<td>300</td>
</tr>
</tbody>
</table>

Table 2: Compare of Biochar-Substrate batches (own design)

→ PAH-content low increase; non-hazardous
→ the total of inorganic pollutant between Small batch and Big batch is comparable
→ All data are under the critical value of the Bio waste Ordinance (including Ni)
## Pot trial – MHC contents

<table>
<thead>
<tr>
<th></th>
<th>MHC</th>
<th>MHC + 10-Vol.% Biochar-Substrate A3</th>
<th>MHC + 50-Vol.% Biochar-Substrate A3</th>
<th>MHC + 50-Vol.% Biochar-Substrate B3</th>
<th>MHC + Biochar (30)</th>
<th>MHC + uncont. Soil, (50)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHC contents</td>
<td>5900</td>
<td>2100</td>
<td>4200</td>
<td>1600</td>
<td>2800</td>
<td>2400</td>
</tr>
<tr>
<td>in mg/kg dry</td>
<td>5400</td>
<td>2000</td>
<td>3900</td>
<td>1500</td>
<td>1900</td>
<td>1900</td>
</tr>
</tbody>
</table>

MHC contents in mg/kg dry matter, **red**: total contents C10 – C40, **blue**: availed content C10-C22

- MHC contents in the mixtures: 960 – 4200 mg/kg dry matter (there was no influence between the amount of interferences and the MHC contents)

- Very high available content of MHC contents: 89 and 95 %, exception: MHC + 14(30) with 53,6 %
**Pot trials - PAH-contents**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>277</td>
<td>184,2</td>
<td>130,2</td>
<td>175,4</td>
<td>183,4</td>
<td>134,7</td>
<td>100,7</td>
</tr>
</tbody>
</table>

PAH-content in mg/kg dry matter

- PAH contents in the mixtures: 130,2 – 184,2 mg/kg TS (there was no influence between the amount of interferences and the PAH contents)

- The highest amounts of PAH contamination, in the pure PAH-soil are fluoranthen (16%), pyren (15%), benzo(a)pyren (10,1%)
Pot trial – growth pattern of the maize plants

growth pattern of the maize type Subito in uncontaminated soil

Picture 10: Pot trial, maize type Subito, uncontaminated soil (Kathrin Rößler)