Determination of degradation rates of organic substances in the unsaturated soil zone depending on grain size fractions of various soil types

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Influence on biodegradation

Rate and extent of biological degradation of organic substances in unsaturated zone influenced by

- Chemical and physical properties of substances
  - Water solubility
  - Toxicity
  - Molecular structure

- Soil-specific properties
  - pH-value, IEC
  - Organic matter
  - Grain size distribution
    - Pore volume, distribution of pore sizes
    - Water content, oxygen supply
    - Transport and storage capacity of water and nutrients
    - Influence on life and growth conditions of bacteria

(Source: http://toolboxes.flexiblelearning.net.au)

Fig. 1 Pore sizes depending on grain size
Characterization of soil pore system

- Description of soil pore system and distribution of different pore sizes with soil moisture retention curve

- Distribution of pore sizes affects the water content, transport and storage capacity of water and nutrients as well as oxygen supply

**Fig. 2** Water retention curve

**Tab. 1** Properties of different pore sizes

<table>
<thead>
<tr>
<th>Pore size range</th>
<th>Equivalent diameter [µm]</th>
<th>Water tension [cm WS, hPa]</th>
<th>[pF]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide coarse pores</td>
<td>&gt; 50</td>
<td>0 – 60</td>
<td>&lt; 1.8</td>
</tr>
<tr>
<td>Narrow coarse pores</td>
<td>50 - 10</td>
<td>60 - 300</td>
<td>1.8 – 2.5</td>
</tr>
<tr>
<td>Mesopores</td>
<td>10 – 0.2</td>
<td>300 - 15000</td>
<td>2.5 – 4.2</td>
</tr>
<tr>
<td>Micropores</td>
<td>&lt; 0.2</td>
<td>&gt; 15000</td>
<td>&gt; 4.2</td>
</tr>
</tbody>
</table>

Source: Weynants et. al (2009); Vadose Zone Journal 8(1)
State of the art and resulting objectives

- Batch experiments with unsteady state conditions
- Better biodegradation with soil that has smaller particles e.g. Zhang and Bouwer (1997)

<table>
<thead>
<tr>
<th>source</th>
<th>saturation (%)</th>
<th>soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pramer, Baratha (1972)</td>
<td>53 - 71</td>
<td>Silty loam</td>
</tr>
<tr>
<td>Dibble, Bartha (1979)</td>
<td>28 - 95</td>
<td>Medium sandy loam</td>
</tr>
<tr>
<td>Dupont et al. (1991)</td>
<td>70 - 93</td>
<td>Medium silty sand</td>
</tr>
<tr>
<td>Briglia et al. (1992)</td>
<td>58 - 82</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>Sims et al. (1993)</td>
<td>30 - 98</td>
<td>Medium sandy loam</td>
</tr>
<tr>
<td>Okeke et al. (1996)</td>
<td>70 - 100</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>Rice et al. (2000)</td>
<td>83 - 100</td>
<td>Sandy clay loam</td>
</tr>
</tbody>
</table>

Determination of the correlation between the grain size fractions respectively pore sizes, water content, oxygen supply and the biodegradation rate of infiltrated organic substances in column experiments
Experimental setup

Fig. 2 Experimental setup
Used grain size fractions

- Determination of pore volume with air pyknometer
  (Source: UGT GmbH)

- Determination of water retention curve/pore sizes with HYPROP system (evaporation method according to Wind (1966) and Schindler (1980))
  (Source: UMS GmbH)

Fig. 3 Grain size distribution curve and used fractions
Selection of organic substances

- Pre-tests with *Sphingobium yanoikuae* and different organic substances (glucose, yeast extract, peptone, starch, oxalic acid, salicylic acid and mixes of those)

- Search for a solution of organic substances which can be culture medium for *Sphingobium yanoikuae*

<table>
<thead>
<tr>
<th>Tab.</th>
<th>Concentrations of used organic substances in the solutions [g/l]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solution 1</td>
</tr>
<tr>
<td>Glucose</td>
<td>1</td>
</tr>
<tr>
<td>Yeast extract</td>
<td>0.5</td>
</tr>
<tr>
<td>Peptone</td>
<td>0.5</td>
</tr>
<tr>
<td>Starch</td>
<td>0.5</td>
</tr>
<tr>
<td>Oxalic acid</td>
<td>0.5</td>
</tr>
<tr>
<td>Salicylic acid</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 4 Growth curve for *Sphingobium yanoikuae* bacteria in solutions with different mixes of organic substances

> Choosing of solution with a mix of glucose, oxalic acid, salicylic acid
First results – pore size distribution

Fig. 5 Distribution of pores sizes in grain size fraction 0.2 – 0.63 mm (A) and 0.63 – 1 mm (B)

- Differences in proportion of wide coarse and micropores
  > Different water contents, transport and storage capacity of water and nutrients, oxygen supply
  > What is the optimal water/oxygen ratio for bacteria?
First results – infiltration and saturation

Fig. 6 Changing of water content due to 3 infiltrations over 24 hours in the soil with grain size fraction 0.63 – 1 mm

Fig. 7 Soil saturation
First results – DOC and oxygen

Fig. 8 DOC for fraction 0.2 – 0.63 mm (A) and 0.63 – 1 mm (B)

Degradation rate: 0.21 d\(^{-1}\)

Fig. 9 Oxygen content for fraction 0.2 – 0.63 mm (A) and 0.63 – 1 mm (B)

Degradation rate: 0.43 d\(^{-1}\)
Summary and outlook

- One of the first column experiments to the influence of pore sizes on the biodegradation

- Higher saturation in soil with smaller grain size fraction

- **Higher degradation rate in soil with bigger grain size fraction**

  Replenishment of nutrients and oxygen has higher influence on degradation than water content

**Outlook:**

- Continuing with fraction 0.063 – 0.2 mm to confirm results

- Repetition of experiments to confirm results
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