Is it possible by using Biogas to make organic agriculture CO$_2$ neutral – and will it have influence on the content of humus in the soil

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Outline

• Introduction
• Influence on nutrient cycles and productivity
• Consequences for the humus budgets and soil biological activity
• Energy- and clima balance
• Conclusions
Stockless System with anaerobic digestion of residues

- Underseed ley
- Clover/grass-ley
- Spring wheat
- Biogas digester
- Cover crop
- Potatoes
- Winter wheat
- Peas
- Winter wheat
- Cover crop
- Cover crop
- Cover crop
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Stockless System with anaerobic digestion of residues

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## Effects on the organic matter and nutrient supply

<table>
<thead>
<tr>
<th></th>
<th>wL</th>
<th>wL-FR</th>
<th>wL-FER</th>
</tr>
</thead>
<tbody>
<tr>
<td>organic DM (t ha(^{-1}))</td>
<td>6.47</td>
<td>2.53</td>
<td>3.08</td>
</tr>
<tr>
<td>C supply (t ha(^{-1}))</td>
<td>3.20</td>
<td>1.40</td>
<td>1.70</td>
</tr>
<tr>
<td>Total N supply (kg N ha(^{-1}))</td>
<td>128</td>
<td>126</td>
<td>154</td>
</tr>
<tr>
<td>Mobile N (kg N ha(^{-1}))</td>
<td>0</td>
<td>104</td>
<td>132</td>
</tr>
<tr>
<td>N supplied to non-legume crops</td>
<td>150</td>
<td>180</td>
<td>223</td>
</tr>
<tr>
<td>N supplied to legumes</td>
<td>83</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>C/N ratio organic manures</td>
<td>25,2</td>
<td>11,0</td>
<td>11,1</td>
</tr>
<tr>
<td>Ammonia-N (kg N ha(^{-1}))</td>
<td>0</td>
<td>43,2</td>
<td>54,5</td>
</tr>
</tbody>
</table>

## Relative impact on crop N uptake (%)

<table>
<thead>
<tr>
<th></th>
<th>wL</th>
<th>wL-FR</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Potatoes</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>WW 3</td>
<td>100</td>
<td>117</td>
</tr>
<tr>
<td>Peas</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>WW 5</td>
<td>100</td>
<td>130</td>
</tr>
<tr>
<td>SW</td>
<td>100</td>
<td>117</td>
</tr>
<tr>
<td>Sum NL</td>
<td>100</td>
<td>116</td>
</tr>
<tr>
<td>Sum cereals</td>
<td>100</td>
<td>122</td>
</tr>
</tbody>
</table>

Stinner et al. 2008
Eur. J. Agron. 29, 125-134
Soil mineral N content in autumn at the beginning of the leaching period (Mean value crop rotation)

Möller and Stinner 2009
Eur. J. Agron. 30,1-16
Sum of soilborne N\textsubscript{2}O-emissions of the crop rotation (\textit{g N\textsubscript{2}O-N ha\textsuperscript{-1} yr\textsuperscript{-1}})

<table>
<thead>
<tr>
<th>Crop</th>
<th>\textit{wL}</th>
<th>\textit{wL}-FR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clover Grass-ley</td>
<td>6,808</td>
<td>844</td>
</tr>
<tr>
<td>Potatoes</td>
<td>2,963</td>
<td>2,217</td>
</tr>
<tr>
<td>Winter wheat 3</td>
<td>761</td>
<td>1,748</td>
</tr>
<tr>
<td>Spring peas</td>
<td>1,399</td>
<td>944</td>
</tr>
<tr>
<td>Winter wheat 5</td>
<td>4,378</td>
<td>3,355</td>
</tr>
<tr>
<td>Spring wheat</td>
<td>1,175</td>
<td>1,800</td>
</tr>
<tr>
<td>(\sum) crop rotation</td>
<td>17,484</td>
<td>10,908</td>
</tr>
<tr>
<td>Mean crop rotation</td>
<td>2,914</td>
<td>1,818</td>
</tr>
<tr>
<td>Relative values (%)</td>
<td>100</td>
<td>62.4</td>
</tr>
</tbody>
</table>
Conclusions: Biogas in a stockless System

- Anaerobic digestion is a tool to get mobile manures, leading to:
  - Significant increase of yields (+16%) and N uptake (+19%) of non-legumes
  - Significant increase of the cereal protein content (+0.6% absolute)

  and simultaneously to a
  - Reduction of the nitrate leaching risk (ca. 20%)
  - Reduction of soilborne N\textsubscript{2}O-Emissions (ca. 40%)

- Driving forces:
  - enhanced N-Inputs via BNF
  - Better allocation of nutrients in space and time
    - Allocation of nutrients in spring when crop N demand arises
    - Higher allocation of available manure-N towards non-legume crops, at the cost of legumes $\Rightarrow$ N allocation more focused
  - Higher NUE of digested residues compared to the undigested substrates
  - lower N losses due to “safe” storage of N during the winter period
Effects of AD of animal wastes, etc. on organic matter and nutrient supply

<table>
<thead>
<tr>
<th></th>
<th>FYM ¹)</th>
<th>US</th>
<th>DS</th>
<th>DS+FR</th>
<th>DS+FER</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soil ODM supply</strong> (t ha⁻¹)</td>
<td>4.9</td>
<td>6.2</td>
<td>6.0</td>
<td>3.7</td>
<td>5.0</td>
</tr>
<tr>
<td><strong>N supplied</strong> (kg N ha⁻¹)</td>
<td>157</td>
<td>172</td>
<td>169</td>
<td>173</td>
<td>216</td>
</tr>
<tr>
<td><strong>Mobile N</strong> (kg N ha⁻¹)</td>
<td>84</td>
<td>90</td>
<td>87</td>
<td>151</td>
<td>193</td>
</tr>
<tr>
<td><strong>Non-Leg.-Manure-N</strong> (kg N ha⁻¹)</td>
<td>225</td>
<td>241</td>
<td>239</td>
<td>264</td>
<td>336</td>
</tr>
<tr>
<td><strong>Legume-Manure-N</strong> (kg N ha⁻¹)</td>
<td>45</td>
<td>55</td>
<td>54</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td><strong>Ammonia-N</strong> (kg N ha⁻¹)</td>
<td>18</td>
<td>40</td>
<td>44</td>
<td>76</td>
<td>85</td>
</tr>
<tr>
<td><strong>C/N manures</strong></td>
<td>15.7</td>
<td>18.4</td>
<td>17.8</td>
<td>11.8</td>
<td>13.0</td>
</tr>
</tbody>
</table>

¹) including dung water (3% of P)
DM yields and N uptake by non-legume crops

Σ DM yield

Σ N uptake

Conclusions: mixed farming system

- **Solid farmyard manure vs. undigested liquid slurry:**
  - DM yields: -5%; N uptake: -8%
  - Nitrate leaching risk: +6%, gaseous N losses: +19%

- **Digestion of liquid slurry (exclusively)**
  - No effects on DM yields after surface banding
  - Significant effects only after incorporation immediately after spreading
  - No effects on overall nitrate leaching risk, tendency to lower SMN contents there where no cover crops were sown
  - Higher ammonia volatilization after surface banding

- **Digestion of liquid slurry and crop residues:**
  - higher mobile manure-N-pool (+54%),
  - Lower nitrate leaching risk (-8%)
  - Higher NUE by non-legumes (+12%)
Inventory of fossil fuel consumption and greenhouse gas emissions
Inventory consumption fossil fuel energy

Inventory greenhouse gas emissions (Michel et al., 2009)

CO₂-equiv-emissions (kg CO₂ ha⁻¹ year⁻¹)

- Series I
  - FYM
  - US
  - DS
  - DS+FR
  - DS+FER

- Series II
  - wL
  - wL-FR
  - wL-FER

- construction and dismantling biogas digester
- means biogas digester
- direct emissions animal production
- means animal production
- direct emissions plant production
- means plant production
- sum/balance
- credit for energy production

Effects on soil organic matter inputs, humus balance and soil biological activity
C-balance of Biogas  (Reinhold et al., 1991)

Carbon available for the long term reproduction of the soil humus pool

\[ \text{without biogas} \quad \text{with biogas} \]

\[ \begin{align*}
\text{37,8 \%} & \quad \text{62,2 \%} \\
\text{63,0 \%} & \quad \text{20,5 \%} \\
\end{align*} \]

\[ \text{C – degradation soil} \quad \text{C - degradation biogas reactor} \]

→ These results were confirmed by Sánchez et al. 2008 and Marcato et al. 2009!
Daily carbon release after soil application of undigested and digested pig slurry

Undigested slurry
Digested slurry
Effects of undigested slurry and digestate application on soil biological activity (microcosm experiment without crop)

- Earthworm Biomass (g*10^{-1})
- Microbial biomass C (μg/g)
- Microbial biomass N (μg/g)
- Basal respiration (μgCO₂-C/100g*h)
- Metabolic quotients

Ernst et al. (2011): SBB 40, 1413-1420
Effects of the manuring system on the microbial biomass, substrat-induced respiration, water extractable C and soil C content after 4 years under field conditions

Schauss et al 2006

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Microbial biomass [μg C g⁻¹]</th>
<th>SIR [nmol CO₂ g⁻¹ h⁻¹]</th>
<th>Water extractable C [10*μg C g⁻¹]</th>
<th>Total C (100 * mg C g⁻¹)</th>
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Influence of manuring on earthworm abundance and biomass under field conditions (mean of 2 experiments)

Conclusions: effects on soil humus and soil biological activity

- Digestion of animal wastes → no effects on soil humus, effects on soil biological activity under field conditions seems to be irrelevant

- Digestion of crop residues and cover crops → unclear, humus balances still very positive due to very large org. matter inputs

- Higher recalcitrancy of organic matter in digestates
Conclusions

- Anaerobic digestion is a very interesting tool to generate renewable energy from residues, however total energy potentials are rather low.

- Enables strategic nutrient management and allocation.

- It resulted in a win-win situation by enhancing yields, creating a new product and reducing the negative environmental impacts of farming activities.

- Effects on the soil humus balance will depend on the performed/replaced cropping system.
Thank you for your attention