Impact of Biochar on Plant Bioparameters and Phytoremediation

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Content

• Introduction

• Impact of Miscanthus biochar as a soil amendment (A review)

• Biochar assisted phytoremediation with $M \times g$ (Laboratory experiment)

• Impact of biochar on plant bio parameters in a field scale

• Conclusions
Introduction

- Biochar assisted phytoremediation with energy crops such as *Miscanthus × giganteus* (*M×g*) in restoring slightly contaminated, marginal land and brownfields is promising.

- Materials from waste sources such as agricultural waste, sewage sludge, wood waste, etc., can be transformed into biochar through slow pyrolysis.

- *M×g* leaves and rhizome waste can be treated and used as soil amendments. The same applies to *M×g* waste derived from processed bio products from its biomass.
Impact of Miscanthus biochar (Pidlisnyuk et al. 2021)

- Biochar parameters including pH, surface area and porosity impact the effectiveness of biochar as a soil amendment.

- These parameters are increased with increasing pyrolysis temperature (max ≈ 700 °C).

- Soil pH and nutrient content (N, P, and K) increases as the application rate of Miscanthus biochar increases.

- Increase in temperature and application rate leads to increase in microbial activity to improve soil conditions.

Application in phytoremediation (Pidnlisnyuk et al. 2021)

- When Miscanthus biochar is amended into soil, it reduces uptake of TEs (Al, Zn, and Pb) by plants.

1 – Houben et al. (2013a)
2 – Houben et al. (2013b)
4 – Novak et al. (2018)
Impact on biomass productivity (Pidnlisnyuk et al. 2021)

- *Brassica napus* L.; Pyrolysis temperature 600; Houben et al. (2013a).
- *Lolium multiflorum* Lam.; Pyrolysis temperature 600; Houben et al. (2013b).
- *Hordeum vulgare* var.; Pyrolysis temperature 600; Fox et al. (2016).
- *Lolium perenne*; Pyrolysis temperature 600; Fox et al. (2014).
- *Spinacia oleracea*; Pyrolysis temperature 500; Khan et al. (2017).
Impact on microbial biomass and soil fauna diversity (Pidnlisnyuk et al. 2021)

### Impact of Miscanthus biochar on soil microbial biomass and soil fauna (feedstock – *M. × giganteus* straw from agricultural land).

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Soil pH before adding biochar</th>
<th>Miscanthus biochar characteristics</th>
<th>Soil pH after adding biochar</th>
<th>Detected effects</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperature, °C</td>
<td>Application rate, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay loam arable land</td>
<td>7.6</td>
<td>360/30</td>
<td>7.7</td>
<td>About 20% of microbial biomass was derived.</td>
<td>Lao et al. (2013)</td>
</tr>
<tr>
<td></td>
<td>3.7</td>
<td>4.4</td>
<td></td>
<td>Microbial colonization was the most.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.6</td>
<td>700/30</td>
<td>0.0</td>
<td>Less than 2% of microbial biomass was derived.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.7</td>
<td>5.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poorly drained gley land</td>
<td>600/15</td>
<td>1.0</td>
<td>6.7</td>
<td>Rhizobacteria and nematodes feeding on bacteria were significantly more abundant in the 2% rate biochar treatment over the 1%.</td>
<td>Fox et al. (2014)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0</td>
<td>7.3</td>
<td>Abundances of rhizosphere soil bacteria were higher in 2% biochar amendment.</td>
<td>Fox et al. (2016)</td>
</tr>
<tr>
<td>Unstony sand soil, with sand</td>
<td>300/15</td>
<td>1.0</td>
<td>6.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silty loam soil, with pure mineral salts</td>
<td>300/15</td>
<td>2.0</td>
<td>7.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow pyrolysis &amp; HTC</td>
<td></td>
<td>1.0</td>
<td>5.8</td>
<td>1% rate of Miscanthus biochar had a bigger effect on the number of bacteria and fungi.</td>
<td>Mierzwia-Henzel et al. (2019)</td>
</tr>
<tr>
<td>Arable field</td>
<td>550/30</td>
<td>30 t ha⁻¹</td>
<td>6.9</td>
<td>No changes in microbial abundance.</td>
<td>Bamminger et al. (2016)</td>
</tr>
<tr>
<td>Silty clay grassland</td>
<td>600</td>
<td>9.3 t ha⁻¹</td>
<td>5.8</td>
<td>Soil microbial biomass was higher with the addition of biochar from pyrolysis than dust of HTC.</td>
<td>Rex et al. (2015)</td>
</tr>
<tr>
<td>Sandy loam soil</td>
<td>200/120</td>
<td>14.5 t ha⁻¹</td>
<td>5.8</td>
<td>Soil microbial biomass was higher with the addition of biochar from pyrolysis than dust of HTC.</td>
<td>Buda et al. (2016)</td>
</tr>
<tr>
<td>Fine loam over clay</td>
<td>450/23</td>
<td>0.6</td>
<td>3.0</td>
<td>Decreasing of larger-size soil fauna (earthworms); increasing of mesofauna. Effect was stronger at higher rates.</td>
<td>Briones et al. (2020)</td>
</tr>
</tbody>
</table>
Biochar assisted phytoremediation

- Laboratory experiment to determine impact of biochar on *M×g* productivity and phytoremediation.
- Soil sampled from an abandoned former coal mining site in Vrsebořice, Czech Republic.
- GPS Location: 50.704351, 13.976142

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (H2O)</td>
<td></td>
<td>4.2</td>
</tr>
<tr>
<td>Available P</td>
<td>mg/kg</td>
<td>12.8</td>
</tr>
<tr>
<td>Available K</td>
<td>mg/kg</td>
<td>722.6</td>
</tr>
<tr>
<td>Available Ca</td>
<td>mg/kg</td>
<td>2279.0</td>
</tr>
<tr>
<td>Available Mg</td>
<td>mg/kg</td>
<td>650.8</td>
</tr>
<tr>
<td>Organic matter</td>
<td>%</td>
<td>27.578</td>
</tr>
<tr>
<td>Total C</td>
<td>%</td>
<td>15.997</td>
</tr>
<tr>
<td>Total N</td>
<td>%</td>
<td>0.592</td>
</tr>
</tbody>
</table>
Experiment design

- A pot experiment throught 154 days (May 5 – October 5, 2024)
- Soils were amended with two different biochars: Food and wood waste biochar (FWB) and sewage sludge biochar (SSB) in two doses: 3.5% and 7%.
- *M*×*g* was cultivated in the pots.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Control</th>
<th>Control</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>FWB</td>
<td>FWB</td>
<td>FWB</td>
<td>FWB</td>
<td>FWB</td>
</tr>
<tr>
<td>3.5%</td>
<td>3.5%</td>
<td>3.5%</td>
<td>3.5%</td>
<td></td>
</tr>
<tr>
<td>FWB</td>
<td>FWB</td>
<td>FWB</td>
<td>FWB</td>
<td>FWB</td>
</tr>
<tr>
<td>7%</td>
<td>7%</td>
<td>7%</td>
<td>7%</td>
<td></td>
</tr>
<tr>
<td>SSB</td>
<td>SSB</td>
<td>SSB</td>
<td>SSB</td>
<td>SSB</td>
</tr>
<tr>
<td>3.5%</td>
<td>3.5%</td>
<td>3.5%</td>
<td>3.5%</td>
<td></td>
</tr>
<tr>
<td>SSB</td>
<td>SSB</td>
<td>SSB</td>
<td>SSB</td>
<td>SSB</td>
</tr>
<tr>
<td>7%</td>
<td>7%</td>
<td>7%</td>
<td>7%</td>
<td></td>
</tr>
</tbody>
</table>
## Biochar characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SSB</th>
<th>FWB</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (H2O)</td>
<td>9.34 ± 0.26</td>
<td>9.87 ± 0.21</td>
</tr>
<tr>
<td>Ash (% dry)</td>
<td>58.57 ± 0.36</td>
<td>8.14 ± 0.98</td>
</tr>
<tr>
<td>Volatile (% dry)</td>
<td>21.32 ± 0.81</td>
<td>8.90 ± 0.54</td>
</tr>
<tr>
<td>Fixed carbon (% dry)</td>
<td>19.63 ± 0.45</td>
<td>79.06 ± 1.38</td>
</tr>
<tr>
<td>C (%)</td>
<td>30.3 ± 3.0</td>
<td>72.8 ± 7.3</td>
</tr>
<tr>
<td>H (%)</td>
<td>1.9 ± 0.19</td>
<td>1.45 ± 0.15</td>
</tr>
<tr>
<td>N (%)</td>
<td>3.22 ± 0.32</td>
<td>1.28 ± 0.13</td>
</tr>
<tr>
<td>S (%)</td>
<td>1.07 ± 0.11</td>
<td>2.04 ± 0.2</td>
</tr>
<tr>
<td>O (%)</td>
<td>62.5 ± 6.2</td>
<td>21.3 ± 2.1</td>
</tr>
<tr>
<td>Sbet (m2/g)</td>
<td>17.4</td>
<td>10.7</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>51.7</td>
<td>62.4</td>
</tr>
<tr>
<td>H/C</td>
<td>0.75</td>
<td>0.24</td>
</tr>
<tr>
<td>O/C</td>
<td>1.55</td>
<td>0.22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TEs</th>
<th>SSB (mg/kg)</th>
<th>FWB (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>19341</td>
<td>963</td>
</tr>
<tr>
<td>Cu</td>
<td>303</td>
<td>293</td>
</tr>
<tr>
<td>Fe</td>
<td>15468</td>
<td>3271</td>
</tr>
<tr>
<td>Ni</td>
<td>35</td>
<td>5</td>
</tr>
<tr>
<td>Pb</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>Zn</td>
<td>1306</td>
<td>12524</td>
</tr>
<tr>
<td>P</td>
<td>44054</td>
<td>2859</td>
</tr>
<tr>
<td>K</td>
<td>3486</td>
<td>3867</td>
</tr>
<tr>
<td>Ca</td>
<td>63360</td>
<td>9466</td>
</tr>
<tr>
<td>Mg</td>
<td>10730</td>
<td>2576</td>
</tr>
<tr>
<td>Mn</td>
<td>1837</td>
<td>84</td>
</tr>
</tbody>
</table>
**Plant productivity**

- **SSB 7%** increased plant height, leaf dry weight (DW), and stem DW, while FWB 7% increased stem DW.
- **Fv/Fm values** peaked in August (0.78–0.80), with the highest values in the control and the lowest in FWB 7%. Stress signs were least in FWB treatment in September.
## TEs and soil pH

<table>
<thead>
<tr>
<th>TEs</th>
<th>mg/Kg</th>
<th>EU Threshold Values (mg/kg)</th>
<th>EU guideline Values (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As</td>
<td>11.8 ± 2.5</td>
<td>5</td>
<td>50-100</td>
</tr>
<tr>
<td>Al</td>
<td>609 ± 10725</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Cd</td>
<td>1.7 ± 1.0</td>
<td>1</td>
<td>10-20</td>
</tr>
<tr>
<td>Cu</td>
<td>40.8 ± 8.8</td>
<td>100</td>
<td>150-200</td>
</tr>
<tr>
<td>Ni</td>
<td>46.2 ± 12.0</td>
<td>50</td>
<td>100-150</td>
</tr>
<tr>
<td>Pb</td>
<td>19.2 ± 2.5</td>
<td>60</td>
<td>200-750</td>
</tr>
<tr>
<td>Zn</td>
<td>56.3 ± 14.1</td>
<td>200</td>
<td>250-400</td>
</tr>
</tbody>
</table>

Al toxicity is an important growth-limiting factor for plants when the concentration is greater than 5 mg/kg in acidic soils (pH < 5.0) and can also occur at pH levels as high as 5.5 in mine spoils (Rout et al. 2001).

Biochar (FWB & SSB) at 7% increases soil pH >5.5.
Experimental field

Experimental field established in 2021 in Chomutov, Czech Republic.

Size: 0.022 ha (220 m²)

Amendments: biochar in two dosages of 5 and 10% (BD1 and BD2), digestate (D), sewage sludge (SS), and hemicellulosic waste (HW)

Planting scheme of M×g experimental field supplemented with different amendments
Year 1 (2021)

Year 2 (2022)

Year 3 (2023)
Biochar incorporation increased plant height and number of tillers of *M×g* cultivated in the marginal land.
### Plant bio parameters

<table>
<thead>
<tr>
<th>Year</th>
<th>Control</th>
<th>BD1</th>
<th>BD2</th>
<th>D</th>
<th>HW</th>
<th>SS</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DW [Green Harvest] (t/ha)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>0.22 ± 0.06</td>
<td>0.23 ± 0.08</td>
<td>0.28 ± 0.03</td>
<td>0.21 ± 0.11</td>
<td>0.24 ± 0.04</td>
<td>0.18 ± 0.04</td>
<td>0.461</td>
</tr>
<tr>
<td>2022</td>
<td>4.61 ± 0.79</td>
<td>5.09 ± 0.93</td>
<td>3.94 ± 2.31</td>
<td>3.11 ± 0.65</td>
<td>3.05 ± 0.46</td>
<td>3.05 ± 0.46</td>
<td>0.047</td>
</tr>
<tr>
<td>2023</td>
<td>11.69 ± 1.80</td>
<td>16.49 ± 2.36</td>
<td>15.87 ± 6.77</td>
<td>12.45 ± 1.45</td>
<td>10.65 ± 1.07</td>
<td>11.21 ± 1.40</td>
<td>0.070</td>
</tr>
<tr>
<td><strong>DW [Brown Harvest] (t/ha)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2023</td>
<td>1.69 ± 0.22</td>
<td>1.80 ± 0.44</td>
<td>2.12 ± 0.86</td>
<td>2.18 ± 0.78</td>
<td>1.46 ± 0.27</td>
<td>2.02 ± 0.29</td>
<td>0.4256</td>
</tr>
<tr>
<td>2024</td>
<td>23.46 ± 5.61</td>
<td>22.31 ± 2.42</td>
<td>22.69 ± 1.97</td>
<td>18.88 ± 4.11</td>
<td>22.52 ± 6.00</td>
<td>18.27 ± 3.41</td>
<td>0.396</td>
</tr>
</tbody>
</table>

- BD1 and BD2 resulted in the increase of DW of harvested biomass of *M×g* by 41.1% and 35.8% respectively in Nov. 2023 (Green harvest 2023).
Conclusions

- pH, surface area and porosity of miscanthus biochar are very important in determining its impact in soil. These factors are increased with increasing pyrolysis temperature till about 700 °C.

- Biochar depending on the application rate can improve soil quality, increase plant productivity, assist in phytoremediation, and improve soil fauna and microbial diversity.

- From the laboratory experiment, the highest dose of biochar from sewage sludge improved plant productivity, whilst biochar from food & wood waste reduced plant stress.

- Highest dose of biochar increased soil pH to reduce the availability of Al.

- Biochar amendment in a marginal land in a field trial resulted in the increase of $M \times g$ plant productivity compared to the control and other soil amendments.
References


Acknowledgement
Thank You!