Combination of biochar adsorption and struvite precipitation for nutrients removal from wastewater and its use as fertilizer

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1.1 Urine separating system

- Collection of wastewater in segregated streams is one of the new concepts in wastewater treatment.
- One such stream is yellow water which is mainly human urine (Beler-Baykal et al. 2009).

- About 80% of the nitrogen, 50% of the phosphorus and 50-60% of the potassium from domestic wastewater come from the urine (Ban and Dave 2004).

- Relieve the burden of WWTPs.
- Reduce eutrophication in freshwater.
- Nutrients reuse in agricultural fields.

Fig. 1. Sketch of source separation and nutrient recovery system
1.2 Nutrients recovery from the separated urine

Obstacles for using urine directly

- The main problem is the storage, transport and spreading of large amounts of urine (Ganrot et al. 2007).
- Its salinity is too high for agricultural and landscape purposes (Beler-Baykal et al. 2011).
- The loss of nitrogen through ammonia evaporation is significant during storage and spreading (Ban and Dave 2004).

Indirect use

- Struvite precipitation
- Adsorption/ion exchange
- Freezing-thawing

- Can also be combined together
1.3 Application of biochar as adsorbent

- Struvite crystallization and zeolite adsorption are usually combined to achieve better recovery efficiency (Ban and Dave 2004).
- However, the main problem is the application after crystallization and adsorption, which required ammonium to be released from exhausted zeolite through desorption (Beler-Baykal et al. 2011).
- The lower recovery efficiency of desorption can affect the final recovery efficiency (Beler-Baykal et al. 2004).

- Biochar can be considered to replace the zeolite as nutrient adsorbent since it can be used directly in agricultural soils without desorption process.

- To use biochar, which comes from biomass waste, to recover nutrients from waste water can bring both environmental and economic benefits.
• 1. Introduction
• 2. Objective
• 3. Materials and Methods
• 4. Preliminary Results
• 5. Conclusions
2. Objective

1. To test the potential of biochar as an adsorbent for nutrients including nitrogen, phosphorus and potassium.

2. To optimize the recovery of P and N from artificial urine through struvite precipitation via MgO addition and NH$_4^+$ and K$^+$ adsorption by biochar.

3. To determine the fertilizing effect of the struvite and exhausted biochar on agricultural soil and plant.
Outline

• 1. Introduction
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• 4. Preliminary Results
• 5. Conclusions
3.1 Materials

- Artificial urine

Table 1  Properties of fresh and stored human urine (Beler-Baykal et al. 2009)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Fresh urine range</th>
<th>Average</th>
<th>Stored urine range</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td>5.8–6.4</td>
<td>6.1</td>
<td>8.9–9.3</td>
<td>9.1</td>
</tr>
<tr>
<td>Electrical conductivity</td>
<td>mS/cm</td>
<td>14.4–16.4</td>
<td>15.4</td>
<td>33.8–40.8</td>
<td>36.7</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>mg/L</td>
<td></td>
<td>744</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium</td>
<td>mg/L</td>
<td>333–540</td>
<td>419</td>
<td>5,740–6,950</td>
<td>6,340</td>
</tr>
<tr>
<td>Potassium</td>
<td>mg/L</td>
<td>966–1,446</td>
<td>1,241</td>
<td>992–1,570</td>
<td>1,213</td>
</tr>
</tbody>
</table>

Table 2  Composition of artificial urine solution in deionised water (Udert, 2003)

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>CaCl_2·2H_2O</th>
<th>MgCl_2·6H_2O</th>
<th>NaCl</th>
<th>Na_2SO_4</th>
<th>KH_2PO_4</th>
<th>KCl</th>
<th>NH_4Cl</th>
<th>CO(NH_2)_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>g/L</td>
<td>0.65</td>
<td>0.65</td>
<td>4.6</td>
<td>2.3</td>
<td>2.8</td>
<td>1.6</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>
3.1 Materials

- **Biochar**

  For $\text{NH}_4^+$ adsorption

Table 3 Properties of biochar used in the study

<table>
<thead>
<tr>
<th>No.</th>
<th>Feedstock</th>
<th>Average Dry Density</th>
<th>Moisture Content</th>
<th>Organic Content</th>
<th>pH</th>
<th>ORP</th>
<th>EC</th>
<th>Zeta Potential</th>
<th>Water Holding Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>g cm$^{-3}$</td>
<td>%</td>
<td>%</td>
<td></td>
<td>mV</td>
<td>mS</td>
<td>mV</td>
<td>% d.w.</td>
</tr>
<tr>
<td>CE-AWP</td>
<td>Wood chip</td>
<td>0.5266</td>
<td>1.98</td>
<td>87.79</td>
<td>7.17</td>
<td>-18.5</td>
<td>0.808</td>
<td>-18.6</td>
<td>80.8</td>
</tr>
<tr>
<td>BS</td>
<td>Wood chip</td>
<td>0.7255</td>
<td>0.33</td>
<td>33.87</td>
<td>8.50</td>
<td>74.2</td>
<td>0.039</td>
<td>-23.7</td>
<td>120.6</td>
</tr>
<tr>
<td>CK</td>
<td>Woody biomass</td>
<td>0.5372</td>
<td>5.66</td>
<td>32.34</td>
<td>9.00</td>
<td>126.6</td>
<td>0.007</td>
<td>-5.75</td>
<td>179.4</td>
</tr>
<tr>
<td>AW</td>
<td>Weathered charcoal</td>
<td>0.4835</td>
<td>66.2</td>
<td>74.49</td>
<td>8.19</td>
<td>-80.1</td>
<td>0.054</td>
<td>-15.4</td>
<td>113.8</td>
</tr>
</tbody>
</table>

- **Magnesium oxide**

  For $\text{PO}_4^{3-}$ adsorption and struvite crystallization
### 3.1 Materials

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>• 150 g each pot</td>
</tr>
<tr>
<td>Biochar</td>
<td>• Biochar from Wood chip&lt;br&gt;• 10g each pot, which is around 12 t/ha</td>
</tr>
<tr>
<td>Pot</td>
<td>• 4 inch diameter and 3.5 inch height</td>
</tr>
<tr>
<td>Seeds</td>
<td>• Bean seeds: Blue Lake (BL)&lt;br&gt;• 5 days for germination and 55 days for harvest</td>
</tr>
<tr>
<td>Nutrients</td>
<td>• N: 0.02g N each pot, which is 25 kg N/ha&lt;br&gt;• P: 0.05g P each pot, 62 kg P/ha&lt;br&gt;• K: 0.063g each pot, 78 kg K/ha</td>
</tr>
</tbody>
</table>
3.2 Methods

- Stuvite crystallization and biochar adsorption

- 5g biochar and 0.5g MgO in 100mL artificial urine, stir for 24h
3.2 Methods

**Pot study**

- Use biochar and struvite as fertilizer

**Pots design**

- **S**: Soil
- **SB**: Soil + Biochar
- **SU**: Soil + Fertilizer (Equal to nutrients in synthetic urine)
- **SUB**: Soil + Biochar (Biochar added to synthetic urine)
- **SUM**: Soil + Struvite (MgO added to synthetic urine)
- **SUBM**: Soil + Biochar + Struvite (Biochar and MgO added to urine)

Table 4. Nutrients applied in each pot (mg nutrients/ 100g soil)

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>Second set</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>S</td>
<td>0.00</td>
</tr>
<tr>
<td>SB</td>
<td>0.00</td>
</tr>
<tr>
<td>SU</td>
<td>20.27</td>
</tr>
<tr>
<td>SUB</td>
<td>30.79</td>
</tr>
<tr>
<td>SUM</td>
<td>25.50</td>
</tr>
<tr>
<td>SUBM</td>
<td>28.92</td>
</tr>
</tbody>
</table>
3.2 Methods

• Application as fertilizer

(1) Biochar and struvite were applied separately and also combined.

(2) Triplicate for all.

(3) Bean seeds were cultivated into the mixed soils.

(4) Experimental conditions such as light, temperature and water were maintained.

(5) Germination percentage and plant growth were recorded.
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4.1 Nutrient recovery process

The addition of MgO resulted in the rapid formation of small crystals.

Needle-shaped crystals became visible on the surface of biochar.

After filtration, biochar with a fine crystalline white powder was obtained.
4.1 Nutrient recovery process

With the addition of biochar, N and P can be removed. The adsorption effects differed with different biochar types, ranged between 17.5 % to 36.4 % of N removal, as well as 4.1 % to 19.7 % of P removal.

With the addition of MgO, mainly P was removed. More than 92.2 % of P and 12.7 % of N was settled.

With the combination of biochar and MgO, nutrient removal efficiency increased significantly, especially for the P removal, from around 10 % with only biochar increased to more than 98 % with MgO addition.
4.2 Kinetics

In the 48 hours of operation, up to 31% of reduction in N concentration in the urine samples due to N removal by biochar was achieved in about eight hours, reaching the final level of 37%.

Independently, the removal of N by MgO addition was not significant, with the removal efficiency of 14%.

The effect of nutrient removal was enhanced with the combination of biochar and MgO significantly, with around 40% of N removal.

Fig. 2. Change of nutrient removal from artificial urine samples with addition of biochar, MgO and their combination in 48 hour: (a) N removal
98 % of P removal by precipitation of struvite could be achieved in a short period of time of less than four hours, reaching the final level of more than 99 % by the end.

Biochar adsorption only removed P in liquid phase by 21 %.

The effect of nutrient removal was enhanced with the combination of biochar and MgO significantly, with more than 99 % of P removal.

Fig. 2. Change of nutrient removal from artificial urine samples with addition of biochar, MgO and their combination in 48 hour: (b) P removal
4.3 Pot study

Experiment

- Second set (Blue Lake 274)
- Nutrients diluted 10 times / Germination tested

- 36 days after seeding
4.3 Pot study

Fig. 3. Germination effects of biochar and struvite application in agricultural soils.

Biochar and struvite amendment increased plant germination percentage.
Fig. 4. Effects of biochar and struvite application on plant growth. Biochar and struvite enhanced plant growth in early stage, which resulted in earlier flower and harvest. However, no significant difference existed in final plant height.
1. Introduction

2. Objective

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4. Preliminary Results

5. Conclusions
5. Conclusions

1. Most of the N and P from urine can be recovered as solids through combined adsorption (by biochar addition) and precipitation (by MgO addition).

2. Results of kinetics study showed that the combination of biochar adsorption and struvite crystallization enhanced the process of nutrient removal, by shortening the time to reach equilibrium concentration to around four hours and improving removal efficiency, with around 40% of N removal and more than 99% of P removal by the end of the experimental run.

3. The results obtained have given positive preliminary indications that recovery of N and P from artificial urine with biochar and MgO could be possible.
   • The mixture of struvite and environmental friendly adsorbent (biochar) has good nutrient qualities and can be used as potential fertilizer.
Thanks!

Questions & Answers