Activated biochar synthesized from Ethiopian Prosopis wood to recycle ammonia off-gassed from source-separated urine

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Maize

Teff

Struvite

Nitrogen-rich biochar

Zerihun Workneh, Mohit Nahata, Xiaoyen Chen, Johannes W. Schwank and Nancy G. Love
Ethiopia has low sanitation coverage; less than 18% of the total population has access to improved sanitation.

(WHO/UNICEF JMP 2013)
The retail price of inorganic fertilizer in Ethiopia is unaffordable for most farmers & increases by up to 20%/yr

Only 10% of the national fertilizer demand was met from 2010-2015

Source: Based on ERHS, 2004 and Robinson 2006.
Insufficiently treated wastewater from treatment ponds and fecal sludge supplies nutrients for agricultural use.
THE 10 LARGEST WASTEWATER TREATMENT PLANTS

LOS ANGELES
CAPACITY PER DAY: 450-MILLION-GALLONS
HYPERION SEWAGE TREATMENT PLANT

DETROIT
CAPACITY PER DAY: 930-MILLION-GALLONS
DETOIT WASTEWATER TREATMENT PLANT

BOSTON
CAPACITY PER DAY: 1.27-BILLION-GALLONS
DEER ISLAND SEWAGE TREATMENT PLANT

CAIRO
CAPACITY PER DAY: 449-MILLION-GALLONS
GABAL EL ASFAR WASTEWATER TREATMENT PLANT

SHANGHAI
CAPACITY PER DAY: 520-MILLION-GALLONS
BAILONGGANG WASTEWATER TREATMENT PLANT

CHICAGO
CAPACITY PER DAY: 1.44-BILLION-GALLONS
STICKNEY WATER RECLAMATION PLANT

WASHINGTON, D.C.
CAPACITY PER DAY: 370-MILLION-GALLONS
BLUE PLAINS WASTEWATER TREATMENT PLANT

PARIS
CAPACITY PER DAY: 449-MILLION-GALLONS
SEINE AVAL PLANT

HONG KONG
CAPACITY PER DAY: 450-MILLION-GALLONS
STONECUTTERS ISLAND SEWAGE TREATMENT WORKS

TOKYO
CAPACITY PER DAY: 406-MILLION-GALLONS
MORIGASAKA WASTEWATER TREATMENT PLANT
Progress on establishing sanitation services in Addis Ababa is slow.

Proposed distribution of sanitation services in Addis Ababa in 2020 (2002 Wastewater Management Master Plan)

- Pit latrine: 37%
- Sewerage: 26%
- Septic tank: 37%
Progress on establishing sanitation services in Addis Ababa is slow

Proposed distribution of sanitation services in Addis Ababa in 2020
(2002 Wastewater Management Master Plan)

Distribution of sanitation services in Addis Ababa, 2011
(AAWSA, 2011)
Expansion of decentralized sanitation services can enhance food security by:

- Managing enteric pathogens to reduce public health risks
- Capturing resources for reuse
Expansion of decentralized sanitation services can enhance food security by:

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Carbon

- Biogas
- Industrial precursors
Expansion of decentralized sanitation services can enhance food security by:

- Managing enteric pathogens to reduce public health risks
- Capturing resources for reuse

**Carbon**
- Biogas
- Industrial precursors

**Inorganic Nutrients**
- Nitrogen content: 70-80%
- Phosphorus: 50-65%
- Micropollutants: ≥50%
Urine as a resource  Material preparation  Ammonia sorption  Future work
Reconsider nutrient flows and how to achieve Resource Efficiency in cities

Conventional “linear” nutrient flow

Mined Phosphorus

Nitrogen Fixation: Haber-Bosch Process

Urine-derived fertilizer & cyclic resource flow

Food

Fertilizer

C

N

P

C

N

P

N₂

CO₂

N₂

CO₂
Ammonia gas can be captured from high pH urine or struvite effluent solutions.
Ammonia gas can be captured from high pH urine or struvite effluent solutions.
Urine as a resource

Material preparation

Ammonia sorption

Future work
Activated biochar was synthesized with methods tailored to resource-constrained settings.

**Powdered prosopis + DAP**

- Room temperature for 3 hours
- Heat @ 80°C for 48 hours

**Precursor prosopis**

\(\text{(NH}_3, \text{H}_3\text{PO}_4, \text{NH}_4\text{H}_2\text{PO}_4)\)

- \(xx = 50, 75 \text{ or } 100 \text{ mg/mL DAP}\)

**Carbonization with air**

- Heat @ 5°C/min to 450°C
- Hold at 450°C for 1 hr

**Prosopis activated biochar**

\(\text{(PSP-xx-POX)}\)

- Cool to room temperature
- Wash ~ 20x deionized water
- Dry overnight @ 110°C

**Also created activated biochar from cellulose using same protocol: AC-xx-POX**
Activated biochar from Ethiopian Prosopis (wood)

Botanic structure of the plant material is preserved post carbonization
Prosopis activated biochar is structurally similar to cellulosic activated biochar

<table>
<thead>
<tr>
<th></th>
<th>Micropore volume (cm$^3$/g)</th>
<th>BET surface area (m$^2$/g)</th>
<th>Total pore volume (cm$^3$/g)</th>
<th>Median pore size (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AC-50-POX</strong></td>
<td>0.312 ± 0.004</td>
<td>666 ± 9</td>
<td>0.319 ± 0.006</td>
<td>0.564</td>
</tr>
<tr>
<td><strong>PSP-50-POX</strong></td>
<td>0.265 ± 0.011</td>
<td>567 ± 19</td>
<td>0.278 ± 0.011</td>
<td>0.560</td>
</tr>
<tr>
<td><strong>Char (no activation)</strong></td>
<td>0.187</td>
<td>388</td>
<td>0.191</td>
<td></td>
</tr>
</tbody>
</table>
Urine as a resource

Material preparation

Ammonia sorption

Future work
Thermogravimetric analysis is used to characterize NH₃ adsorption and desorption.
PSP-50-POX activated biochar has ammonia sorption characteristics comparable to cellulosic activated biochar.
PSP-50-POX activated biochar has ammonia sorption characteristics superior to Zeolite.
Diffuse Reflectance Infra-Red Fourier Transform Spectroscopy (DRIFTS) spectra for activated biochar and activated prosopis biochar showing evidence for ammonia binding.
Ammonia off-gas from high pH urine was captured on activated biochar.
Strongly physisorbed NH$_3$ can be released when biochar is submerged in water, suggesting bioavailability for plants.
Work has continued in Ethiopia
Urine as a resource

Material preparation

Ammonia sorption

Future work

• Scale up volume of biochar synthesized
• Evaluate alternative activating chemistry
• Plant studies with indigenous crops
To date, we’ve shown:

• Activated biochar can be synthesized in modest semi-batch reactors in presence of air, without the use of solvents, leading to the possibility of its small scale production in low resource settings

• Activated biochar made from the Ethiopian prosopis tree has characteristics comparable to cellulosic sources available in the U.S.

• Acidic surface functionalities make DAP-activated biochar suitable for adsorbing NH$_3$

• Adsorbed NH$_3$ can be easily recovered, implying bioavailability for plants.
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Urine separation is a growing practice around the world