Circular Bionutrient Economy: Fertilizer Derived from Human Waste

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Abstract

The Circular Bionutrient Economy (CBE) is a way of rethinking outdated systems of sanitation and food security. Waste, rather than being a problem that needs to be disposed of, can be used as a valuable resource. There are countless innovative ways to "close the loop" between waste streams and resources necessary to human survival. This paper explores one such way that nitrogen, phosphorus, and potassium from human waste can be turned into agricultural fertilizer.

Introduction

Using human excreta as agricultural fertilizer is not a novel or untested strategy (Martin et al. 2022). However, depending on scale and location, there are a few logistical concerns with the direct application of human waste on agricultural lands. Urine is mostly water and thus transporting it over long distances is costly and energy intensive. Furthermore, the pH and salinity of urine is above what plants typically need to thrive (Martin et al. 2020). Depending on location, human waste can contain higher levels of PFAS and pharmaceuticals than what is recommended to apply to agricultural lands. Certified organic agriculture also prohibits the application of sewage sludge due to possible contaminants in the substance (McEvoy 2011). Finally, massive stigma exists around human excreta. People immediately assume that any application of human excreta applied in agricultural contexts poses a massive threat to human health.

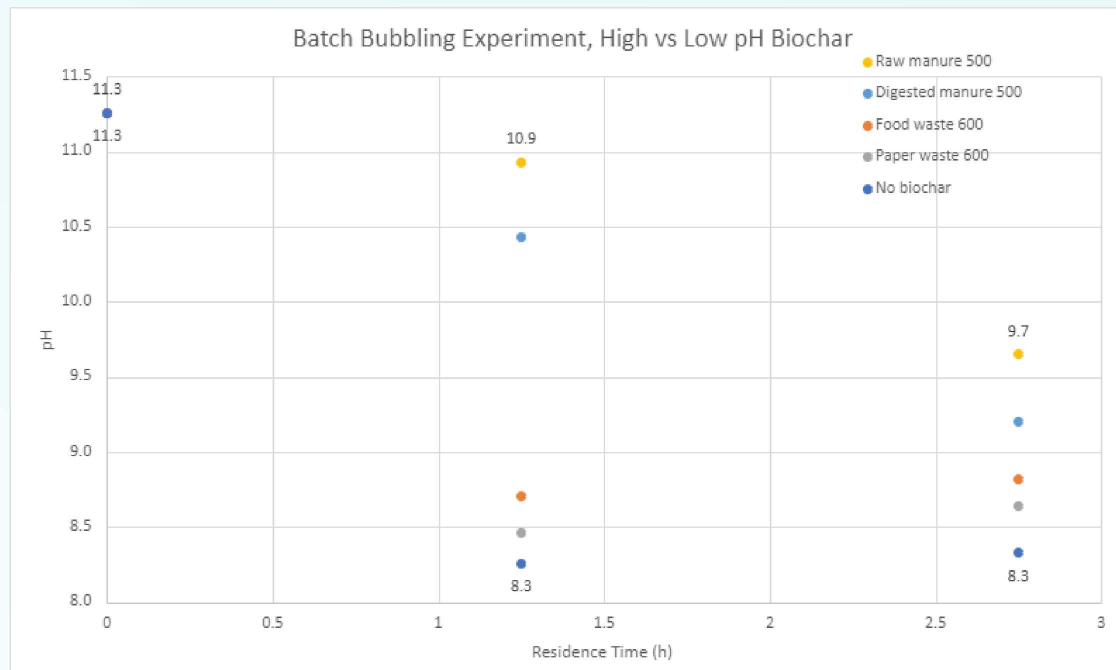
To address these issues, we built a reactor to capture nitrogen, phosphorus, and potassium (NPK) from human urine and store it on clean biochar. Biochar is a carbon rich soil amendment made through the process of burning organic matter in the presence of low or no oxygen, known as pyrolization. The result is an extremely porous material that can absorb nutrients and act as a slow release fertilizer (Wang 2022). While biochar can be made from any number of substances, we specifically favor using biochar from human biosolids (i.e solids from a wastewater treatment plant) and dairy manure solids to further the prospects of turning waste into valuable resources.

Methodology

Batch Bubbling Experiment

To determine the chemical buffering effects of biochar on NH4OH solutions

- NH4OH solutions were adjusted to pH 11. When air is bubbled through ammonium, the pH of the liquid naturally drops as ammonia volatilizes.
- Five bubbling solutions were set up simultaneously: two naturally high pH biochars (raw manure and digested manure solids), two lower pH biochars (food waste and paper waste), and a no biochar control.
- The biochar to water ratio was 1:15
- Experiments ran for 3 hours and pH data was collected every 30 minutes.



Graph depicting pH over time for air bubbled through solutions of biochar and water

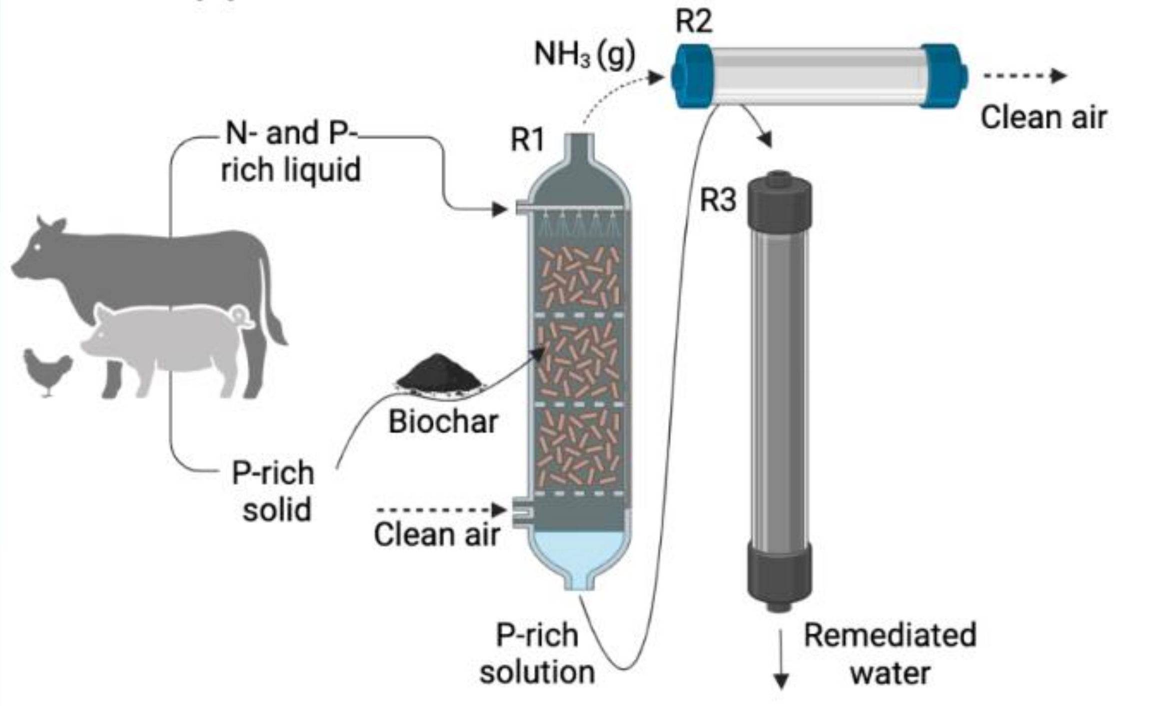
Image of ammonia volatilization reactor set up in fume hood.

Reactor Experiments

The ammonia volatilization reactor was built using PVC pipes, tubing, a peristaltic pump, air valve, 1.5 g NH4OH solution, and an H2SO4 acid trap. We used a packed bed reactor design with downward water flow and upward airflow. The material inside the reactor was biosolids-based biochar in 2-4 mm pieces. While running our experiments, the peristaltic pump was set to 2 (approximately 100 mL/min) and the air valve was set to 10 L/min. While it was typically our intention to leave the reactor running for 24 hours, we encountered significant issues with our reactor leaking. We tried to remedy this with sealing tape, but sometimes the leaking became too intense and we had to stop the experiment early. Experiments ultimately lasted 3.5-45 hours dependent on reactor design and leaking dilemmas.

To analyze nitrogen levels of our samples, we used photospectroscopy. All samples were acidified or made basic to be in the range 4-7 pH using H2SO4 or NaOH. The samples were then diluted using hypothesized ranges of nitrogen levels. In this method, sodium salicylate was the primary reagent that was used to cause the color reaction with ammonium. Samples were compared to an ammonium stock solution made from NH4Cl with standard amounts of Nitrogen.

In our first experiment we used non pH adjusted biochar as the packing material for this reactor. The pH of this biosolids based biochar was 7.6. For the next experiment, we adjusted the pH of the biochar to 10.89. For the final experiment, we used pH adjusted biochar and added NaOH to the NH4OH solution every hour to stabilize the pH through the experiment. The process of nitrogen volatilization naturally lowered the pH of the solution. For future reactor runs we are looking to add a pH probe to our solution tank and an Arduino controlled pH adjustment system to continually add NaOH.



Full reactor set up in a dairy farm application. In place of animal manure, human waste from a wastewater treatment plant can also be used as it is similarly high in N and P.

Results

Through the batch scale bubbling experiment, we determined that high pH manure-based biochar did a better job at buffering in the solution and kept the pH of the NH4OH solution higher for longer. The lower pH biochars also had a positive effect on the pH as compared to the no-biochar control.

We found that pH-adjusted biochar with continuous, manual pH adjustment resulted in 93% nitrogen removal over 3.5 hours. This is an improvement from previous experiments without any biochar adjustment that only resulted in 85% removal over 45 hours, or only biochar pH adjustment that resulted in 85% removal over 5 hours.

However, after running mass balance analysis on our data, it was found that between reactor run experiments, the biochar was holding onto some amount of Nitrogen and releasing it during the next experiment.

Mass balance for pH adjusted BC & Continual pH adjustment

Time	NH4OH N removed	H2SO4 N accumulated	% removed	% accumulated of removed
0-30mins	776.0	1927.3	23%	248%
30-60mins	799.3	3036.8	46%	380%
60mins-2h	1126.9	2047.8	79%	182%
2h-3.5h	500.8	1907.5	93%	381%
Total	3203.0	8919.4	93%	278%

Biochar pH	Continual pH adjustment?	% Nitrogen Removal
Non-adjusted	No	85% in 45 hours
Adjusted to 10.89	No	85% in 5 hours
Adjusted to 11.64	Yes (manually)	93% in 3.5 hours

Conclusion

In the early 20th century with the Green Revolution, agricultural practices changed dramatically. Farms grew in size, shifted towards only growing one type of crop, and increased their dependence on synthetic fertilizers (Pingali 2012). The results were outstanding! At a time when it was unclear how agriculture was going to keep up with a rapidly increasing global population, the Green Revolution solidified global food security. Similarly, the toilet and modern sanitation infrastructure is considered one of the greatest inventions of all time, saving lives through the prevention of the spread of disease. There is no debate that these inventions changed the course of history for the better.

However, these same inventions that saved countless lives are now impeding our planet's ability to thrive into the future. The Haber-Boche process, which allows for ammonia (nitrogen in a plant-available form) to be synthesized from nitrogen in the atmosphere, currently accounts for around 1% of global energy consumption and 1.4% of global CO2 emissions (Capdevila-Cortada 2019). It is imperative that we work towards fundamentally shifting sanitation and food production systems away from practices that exacerbate ecological distress and towards ecological resilience

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