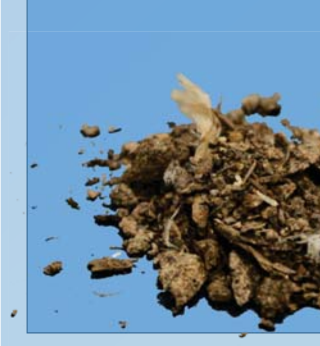

Recovery of Nutrients from Chicken Litter to Create a Slow-Release Fertilizer

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Abstract

Large loads of nutrients are introduced to the Chesapeake Bay from agricultural runoff, fueling the growth of algal blooms and jeopardizing water quality and the ecological health of the Chesapeake Bay and its tributaries. Recently enacted regulations in Maryland have made it increasingly important to remove nutrients, namely nitrogen and phosphorus, from chicken litter. For that reason, we have devised a nutrient recovery process, in which chicken litter is mixed with water to form a high-solids slurry. The pH of this slurry is decreased to approximately 4.3 by bubbling carbon dioxide and dosing hydrochloric acid; at this pH, nitrogen and phosphorus are released from litter solids, generating a nutrient-rich solution. After solid-liquid separation, the pH of the nutrient-rich solution is increased to 8.8 through addition of sodium hydroxide. At this pH, struvite ($MgNH_4PO_4 \cdot 6H_2O$), which is a slow-release fertilizer, precipitates. Trace amounts of other nutrient-laden minerals, such as potassium struvite, hydroxyapatite, newberyite, and monetite, are also generated. We postulate that nutrient loads to the Chesapeake Bay can be drastically reduced by implementing this nutrient recovery process, and that the recovered struvite can serve as an alternate source of phosphorus.

Background

Runoff from agricultural areas is one of the major contributors to high levels of nutrients, such as phosphorus and nitrogen, in water supplies. Large amounts of these nutrients spur the growth of algal blooms, which grow in the water column, consume dissolved oxygen, and block sunlight from reaching submerged aquatic vegetation (SAV). This situation diminishes SAV populations and results in less water filtration, impacting aquatic organisms and biodiversity as well as recreational enjoyment of waterways by humans. New laws in Maryland set limits on the amount of phosphorus and nitrogen that can enter the Chesapeake Bay watershed. Generation of slow-release fertilizers from the phosphorus found in chicken litter will not only help to reduce the amount of nutrients discharged to local watersheds, but also provide a sustainable waste management and recovery program for phosphorus.

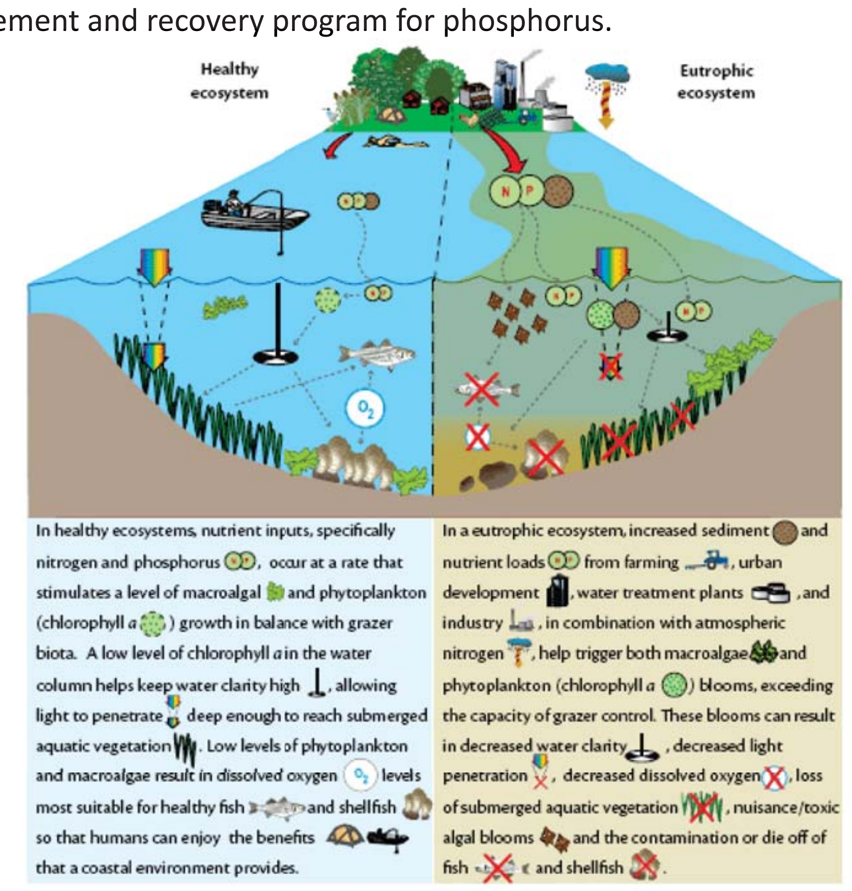

Figure 1. Summary of nutrient impacts on water bodies. Source: *The Ohio River H.A.B.* Kentucky Waterways Alliance.

Experimental Methods

The following protocols were employed:

- Chicken litter from Chesapeake Bay poultry farms was dried at 50°C and sieved before being mixed with deionized water at 100 g/L.
- $CO_2(g)$ was bubbled into the chicken litter slurry and hydrochloric acid was added until the pH was ~4.3.
- After a sufficient contact time, the chicken litter slurry was centrifuged to isolate phosphorus-rich liquid and remove nutrient-deficient solids.
- Air was bubbled into the nutrient-rich solution and base (NaOH) was added until pH ~8.8, where struvite ($MgNH_4PO_4 \cdot 6H_2O$) and potassium struvite ($MgKPO_4 \cdot 6H_2O$) precipitated. Solids were isolated through centrifugation.
- Phosphorus was measured using the stannous chloride standard method.

Results and Discussion

Nutrient extraction and recovery

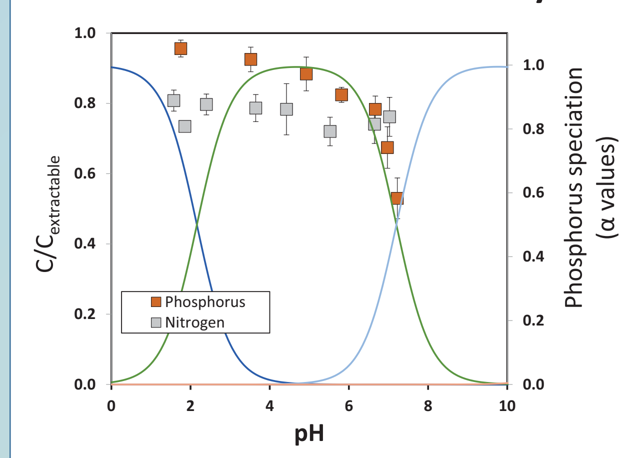

Figure 2. Phosphorus and total nitrogen extraction efficiencies are plotted as a function of pH. All experiments were conducted in triplicate. Optimal extraction of phosphorus and nitrogen occurs at pH ~4.3. Further decreases in pH provide phosphorus extraction, but the operating costs become limiting.

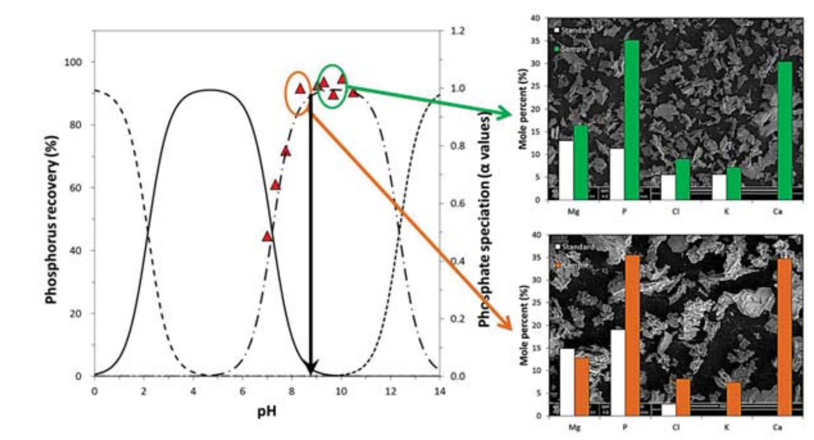

Figure 3. Phosphorus recovery efficiency is plotted against pH; furthermore, SEM images are shown for recovered products, including struvite and potassium struvite. The phosphorus recovery efficiency increases with pH, and the optimum operating condition is at pH ~8.8. At this pH, struvite and potassium struvite precipitate. The EDS analysis of the recovered products verify the incorporation of phosphorus, nitrogen, and potassium.

Reducing acid costs

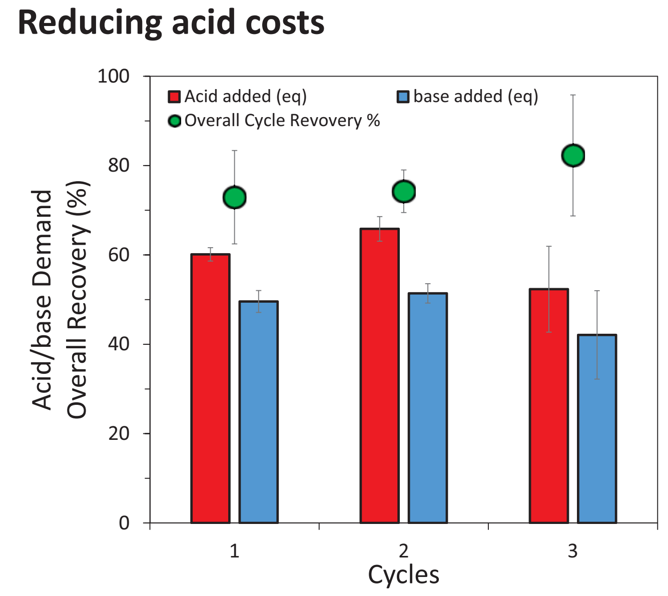

Figure 4. The acid and base demands associated with operation of the phosphorus extraction and recovery process are shown for three cycles. Note that the acid and base demands identified here correspond to the 100 g/L chicken litter slurries and operational set points of 4.3 and 8.8.

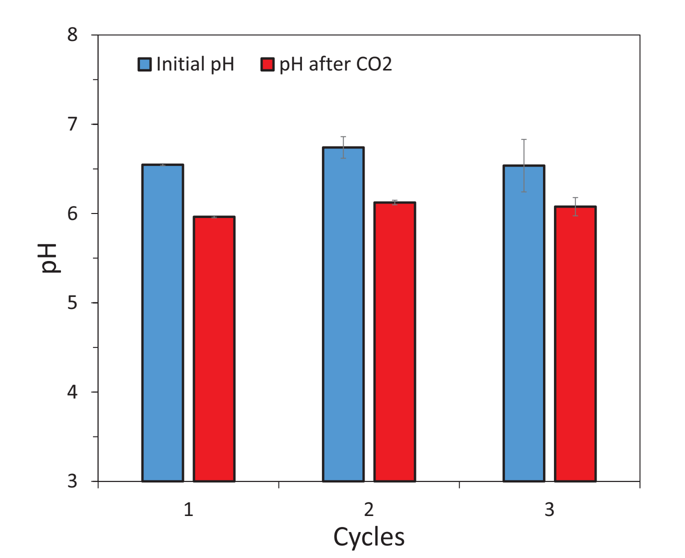

Figure 5. Effect of $CO_2(g)$ bubbling on pH in the extraction reactor. Findings show that CO_2 bubbling lowers the pH of the system to approximately 5.8-6.1 for cycles 1-3, effectively reducing the strong acid demand. Furthermore, this strategy increases the sustainability of the system by utilizing waste CO_2.

Assessing recovery efficiency and decreasing water use

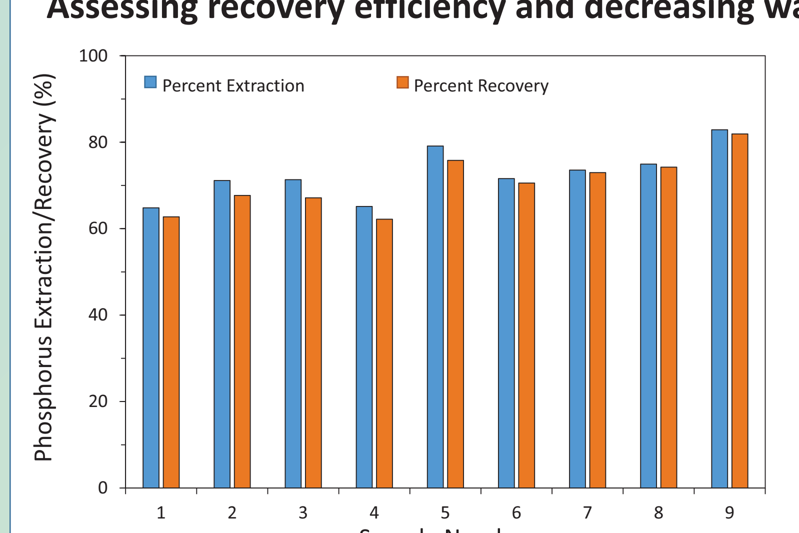

Figure 6. Phosphorus extraction and recovery efficiencies for RCP chicken litter. These data show that phosphorus was effectively extracted from chicken litter, and recovered as a high-value fertilizer product. Sample number refers to replicate measurements (*i.e.*, samples 1, 2, and 3 stemmed from an experiment with three cycles of water reuse, see Figure 7; samples 4-6 and 7-9 were collected from replicate experiments), with all other conditions remaining the same. In this case, the extraction efficiency was consistently in the 60-80% range with high precipitation efficiencies (> 90%).

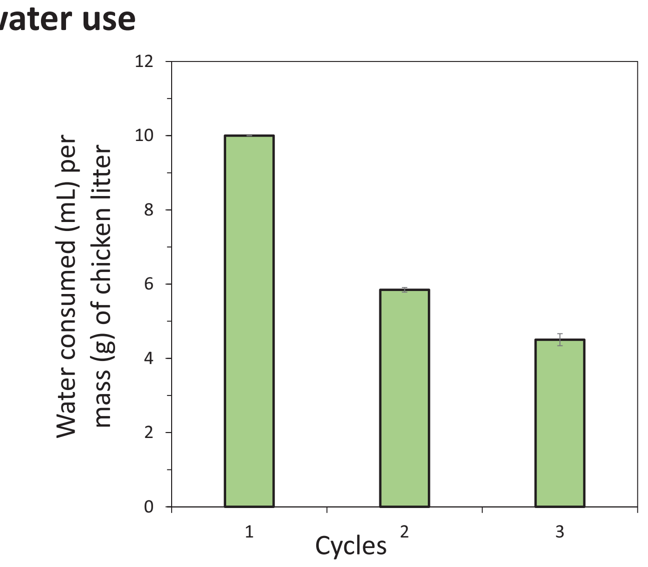

Figure 7. Reusing the process effluent increases the effective water usage and decreases discharge. The second and third cycles were run using recycled effluent from the previous cycle. As evidenced by the data, the amount of water needed for nutrient extraction and recovery decreases with reuse. This strategy reduces the cost of the process and the amount of wastewater generated during nutrient recovery.

Schematic of Phosphorus Extraction and Recovery System (PEARS)

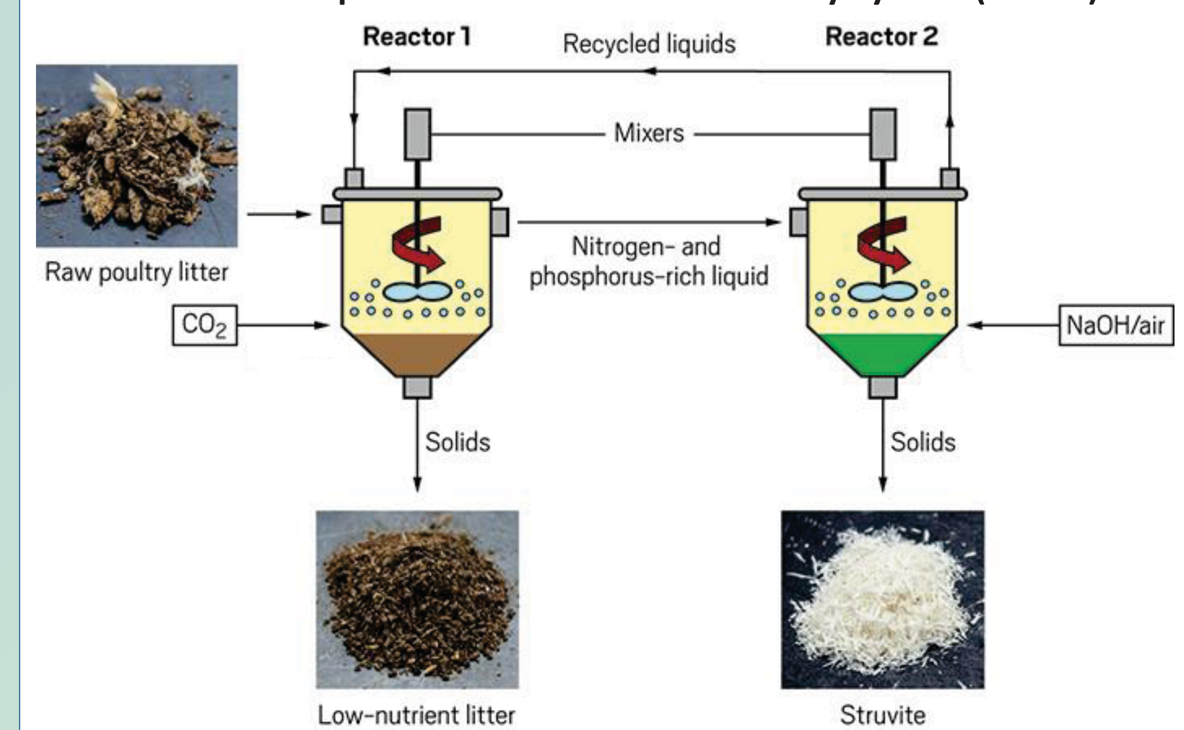

Figure 8. A schematic of the Phosphorus Extraction and Recovery System (PEARS) used in this research. The diagram shown here stems from a recent C&EN news article, "How to get the good stuff out of chicken manure" by Michael Torrice (C&EN 94(16), 21-22), documenting our work and highlighting its impact on Chesapeake Bay poultry farmers. In this case, raw chicken litter is the major input, with a low-nutrient litter and struvite-based minerals being the main products.

Future Work

- In the future, I aim to complete additional research on decreasing the effective water usage through optimization of the nutrient recovery process to produce a self-operating system that generates a low volume of wastewater.
- Additionally, I want to investigate alternative acids to be used in the phosphorus extraction step and alternative bases for the phosphorus recovery stage, to decrease the costs associated with HCl and NaOH.
- Finally, I want to improve the chemistry of the recovery process so that struvite is the most abundant product, and that calcium-based precipitates, like hydroxyapatite, are minimized.

Conclusions

Due to both sustainability and political security concerns, the need to reduce the amount of agricultural waste and pollution is paramount. By implementing the phosphorus extraction and recovery process, between 70 to 80 percent of the phosphorus in chicken litter can be removed (which decreases the amount of phosphorus entering waterways via agricultural runoff), and then reused to create a slow-release fertilizer in the form of struvite (which will also reduce the amount of phosphorus entering sensitive watersheds by improving fertilizer use). The slow-release fertilizer releases nutrients, such as phosphorus, when the plant needs them; therefore, nutrients are not immediately lost through irrigation practices and rainstorms. The improvements identified here, namely implementation of CO_2 bubbling and water reuse, have improved the efficiency of the nutrient recovery system, optimized phosphorus recovery, and minimized the operating costs.

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