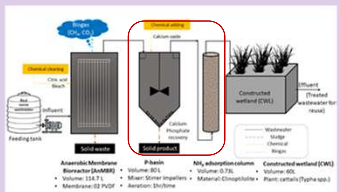
Sequential Nutrient Recovery From Anaerobic Membrane Bioreactor Treated Swine Wastewater (Sequestering Fertilizers From Livestock Wastes)

Department of Civil Engineering, Kansas State University, Manhattan, Kansas
Parnian Mohammadian, Elinor Steinbach, Huu Tuan Tran, Prathap Parameswaran, Jack Murphy, Ganga Hettiarachchi

Background

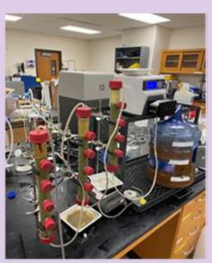
Global food security relies on nitrogen (N) and phosphorus (P) fertilizers. However, current N production is energy-intensive, and P is a finite mineral resource. Furthermore, up to 70% of applied nutrients are lost to the environment, causing pollution and increased costs. To address this, sustainable resource recovery from nutrient-rich waste is essential. We use an Anaerobic Membrane Bioreactor (AnMBR) platform to treat swine wastewater, generating a particle-free permeate ideal for tailored recovery. Our work demonstrates a novel sequential recovery approach:



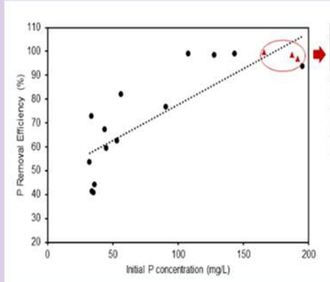
Setup Description

Dual Nutrient Recovery starts with ammonium (NH_4^+) capture using natural clinoptilolite packed into three glass columns in series. Swine permeate is fed upward at a constant rate via peristaltic pump, with flow controlled by a predictive model to maintain effluent NH_4^+-N below 25 mg/L.

For sequential phosphorus recovery, the permeate is first pretreated in batch reactors by adjusting pH to ~4.5 with HCl and aerating for one hour to strip CO_2 and minimize carbonate interference. Calcium oxide is then added, and the mixture is stirred for 5 hours before settling for 7 hours to allow floc formation, CaP precipitation, and sedimentation. Solids are collected from the basin bottom, centrifuged, and recovered as fertilizer product.

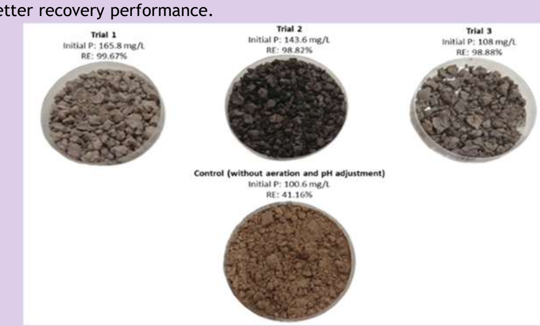


Results

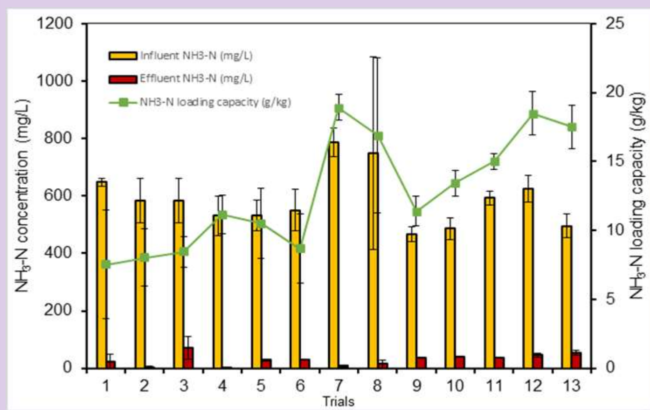


Samples	Total P (mg kg^{-1})	Total P (%)	Citric P %	Mass (g)
Trial 1	133250	13.325	32	2.616
Trial 2	114390	11.439	38.68	12.27
Trial 3	136260	13.626	33.3	11.96

Above Graph demonstrates a correlation between initial P concentration (mg/L) and P Removal Efficiency (%), indicating that higher starting concentrations lead to better recovery performance.



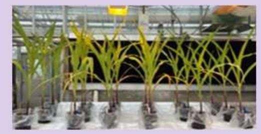
Above Graph Comparative P recovery showing the distinct recovered material from Trials 1, 2, and 3—all achieving superior efficiency (recovery~99%) versus the significantly lower-performing control (recovery which lacked aeration and pH adjustment

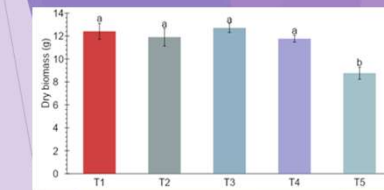


Above Graph: Schematic of Ammonia capture efficiency and loading capacity for clinoptilolite

Results (continued)

Treatments	
T1	100% urea
T2	90% urea + 10 % clinoptilolite
T3	80% urea + 20% clinoptilolite
T4	100 % clinoptilolite
T5	Control with no added N





Above Graph shows Clinoptilolite vs. Urea as fertilizers. Substituting urea with the recovered clinoptilolite (Treatments T1-T4) did not negatively impact the final dry biomass of the corn plants when compared to 100% urea (T1).

Conclusion

This research confirms the successful implementation of an integrated, dual-product recovery platform from AnMBR-treated swine wastewater. The platform efficiently recovered both nitrogen (N) and phosphorus (P), transforming a complex waste stream into high-value resources. For N recovery, a predictive model effectively guided adsorption onto clinoptilolite, achieving efficient and controlled ammonia removal. For P recovery, the key challenge of carbonate interference was successfully overcome via controlled acidification and aeration. Crucially, it was observed that higher influent P content correlated with higher removal efficiency. This optimized method successfully produced high-value calcium phosphate fertilizer.

This demonstrates that customized nutrient recovery is technically feasible and highly efficient, providing a compelling model for resource circularity. Future work should prioritize techno-economic analysis and pilot-scale testing to validate long-term commercial viability.

Future Plans

- **Clinoptilolite Regeneration and Performance**: Investigate the regeneration of spent clinoptilolite to establish a sustainable, cyclic operation. This includes assessing the effect of regeneration on subsequent ammonium adsorption efficiency and capacity.
- **Process Optimization for Extended Operation**: Optimize the column setup to achieve a significantly longer breakthrough time.
- **Large-Scale Applicability and Validation:** Utilize the optimized findings) to inform and conduct pilot- or full-scale studies. This step is essential for validating the system's performance, stability, and techno-economic feasibility under real-world, large-volume conditions.

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