A Sustainable Cellulose/Clay Aerogel Platform for On-Farm Nitrate Removal and Monitoring in agriculture Wastewater

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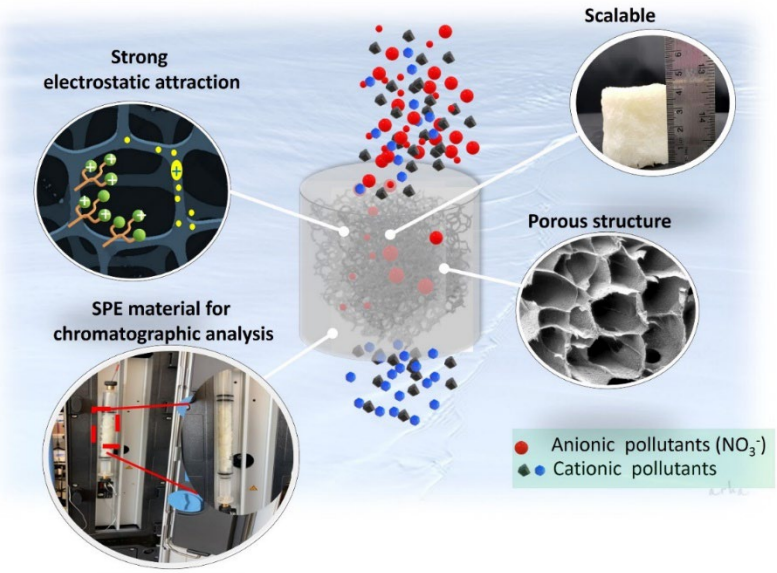
***Abstract*:**

Excess nitrate loading from dairy manure wastewater poses a persistent threat to groundwater quality, ecosystem health, and regulatory compliance in intensive agricultural regions such as California's Central Valley. Here, we report the design of a sustainable, bio-based, and field-deployable cationic aerogel platform that integrates materials science innovation with agricultural water management needs. A hybrid cationic aerogel (CPC-MT@QMCC) was fabricated by entrapping cetylpyridinium-modified montmorillonite within a quaternized microcrystalline cellulose matrix, yielding a lightweight (10.6 $mg.cm^{-3}$), highly porous (≈70%), and mechanically robust three-dimensional network. The aerogel exhibited exceptional nitrate adsorption capacity, rapid kinetics (<30 min), and high dynamic binding efficiency (≈710 mg g^{-1}), outperforming commercial ion-exchange resins under comparable conditions. Importantly, the material demonstrated excellent regeneration, structural stability, and >95% nitrate recovery over multiple cycles, enabling both treatment and nutrient recovery. Application to real dairy manure wastewater achieved up to 96% nitrate removal and enabled preconcentration with a detection limit of 0.1 $mg.L^{-1}$, supporting regulatory monitoring requirements under nitrate control policies. The scalability, low production cost, and compatibility with on-farm treatment systems position this aerogel as a practical solution bridging advanced materials, agricultural outreach, and policy-driven water quality management for sustainable nutrient control in livestock operations.



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