Investigating the Use of Biochar for Nitrate and Ammonium Removal from Aqueous Solutions

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Introduction

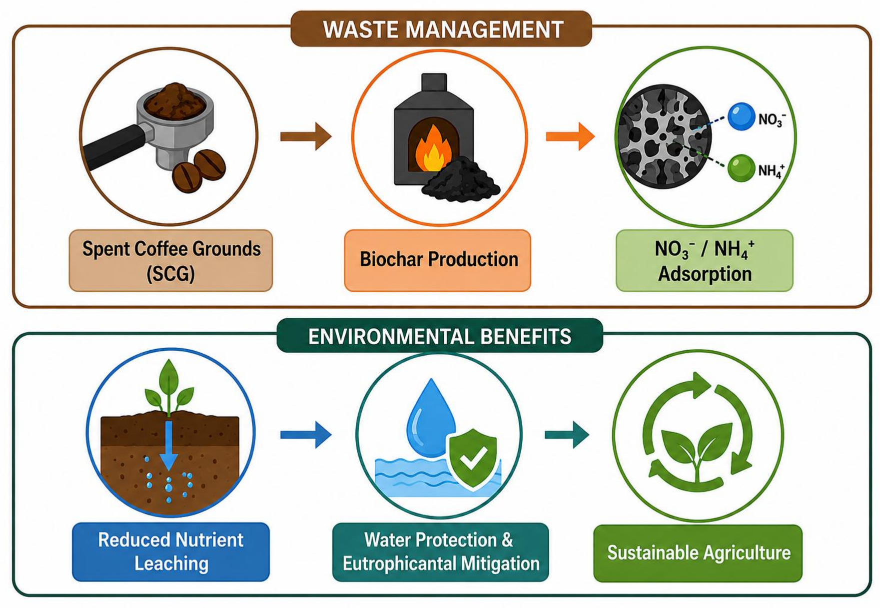
Spent coffee grounds (SCG), generated in large quantities by coffee shops and food-service activities, represent a significant organic solid waste stream that is often underutilized or disposed of in landfills [1]. The valorization of SCG through thermochemical conversion into biochar offers a sustainable waste-management strategy aligned with circular-economy principles, promoting waste minimization, resource recovery, and the production of value-added materials [2].

Biochar possesses a highly porous structure, a large specific surface area, and diverse surface functional groups, which enhance its ability to retain and adsorb nutrients and contaminants [3]. In agricultural systems, losses of nitrate (NO_3^-) and ammonium (NH_4^+) through leaching contribute to groundwater contamination, eutrophication of surface waters, and reduced nutrient-use efficiency [4].

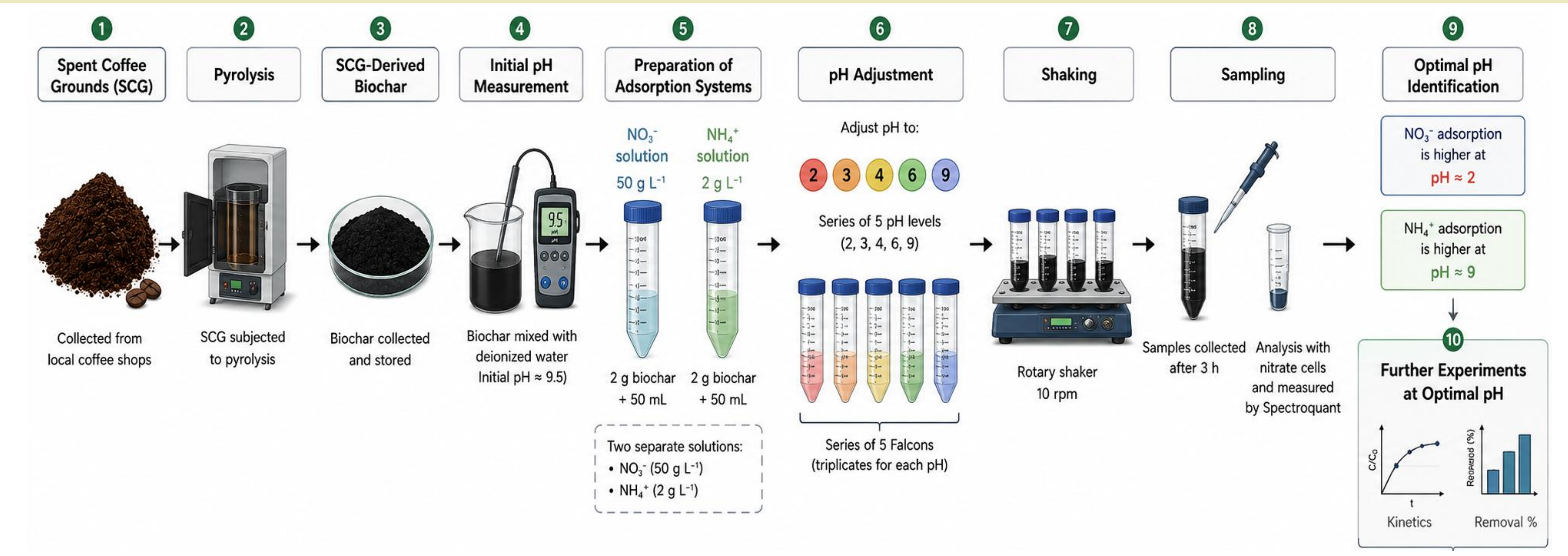
In this context, SCG-derived biochar may provide dual environmental benefits:
(i) sustainable management and valorization of organic solid waste streams and
(ii) mitigation of nitrogen losses through the adsorption of nitrate and ammonium ions.
Such an approach supports circular economy principles by converting waste into a functional material that can improve nutrient management, reduce environmental pollution, and enhance the sustainability of agricultural systems.

Aim of the current research

To assess the potential of SCG biochar for NO_3^- and NH_4^+ adsorption, promoting sustainable nutrient management and waste valorization within a circular economy framework



Materials and Methods



Results

Effect of pH on NO_3^- and NH_4^+ Removal

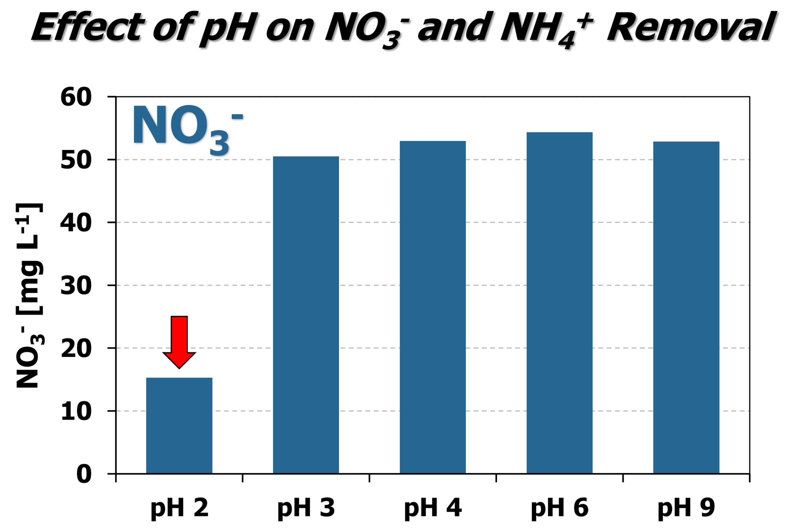


Fig. 1: Effect of pH on nitrate removal by SCG-derived biochar. Experiments were conducted at an initial nitrate concentration of 50 mg L^{-1} and a contact time of 3 h. The highest nitrate removal was achieved at pH 2.

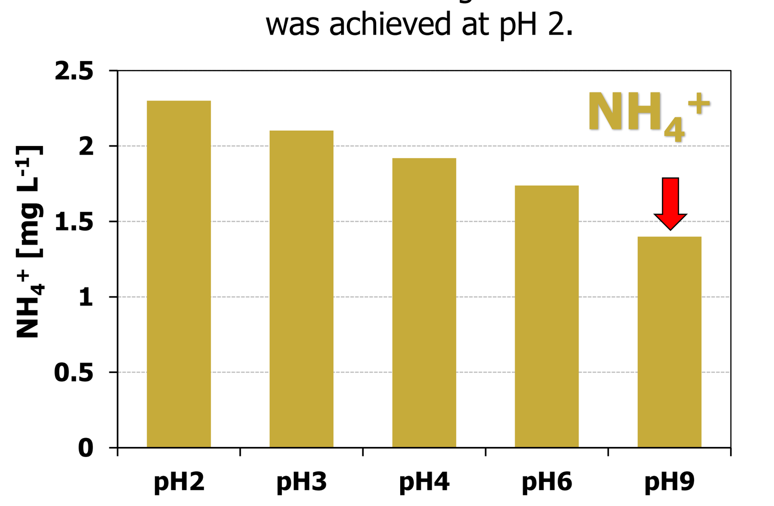


Fig. 2: Effect of pH on ammonium removal by SCG-derived biochar. Experiments were conducted at an initial ammonium concentration of 2 mg L^{-1} and a contact time of 3 h. Maximum ammonium removal was observed at pH 9.

Effect of Contact Time on NO_3^- and NH_4^+ Removal

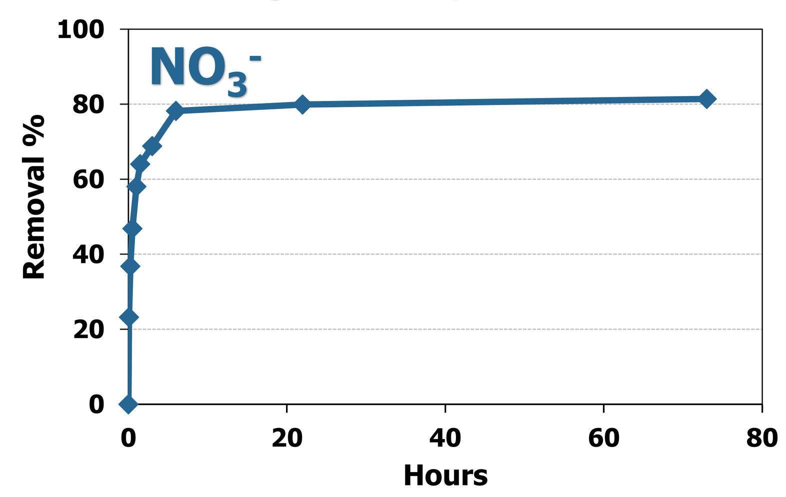


Fig. 3: Effect of contact time on nitrate removal by SCG-derived biochar at the optimum pH (pH 2). Nitrate removal increased rapidly during the initial adsorption stage, reaching 68.8% after 3 h.

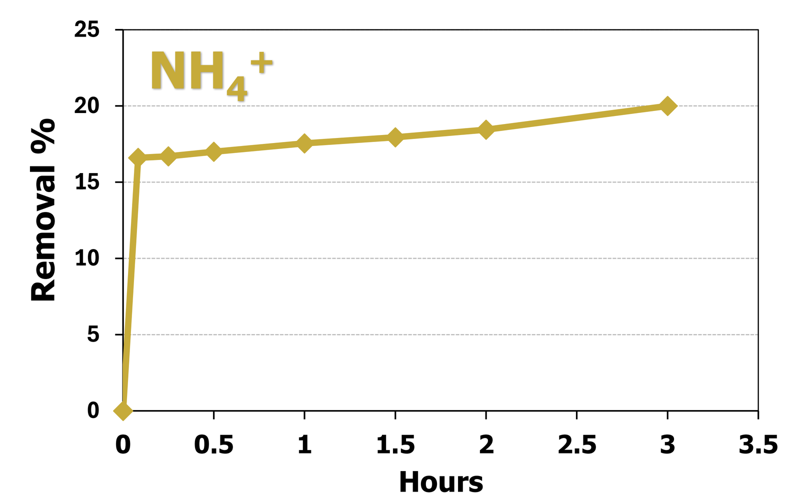


Fig. 4: Effect of contact time on ammonium removal by SCG-derived biochar at the optimum pH (pH 9). Ammonium removal increased gradually with contact time, reaching 20% after 3 h.

Effect of Contact Time on Nitrate Adsorption Capacity (q_t)

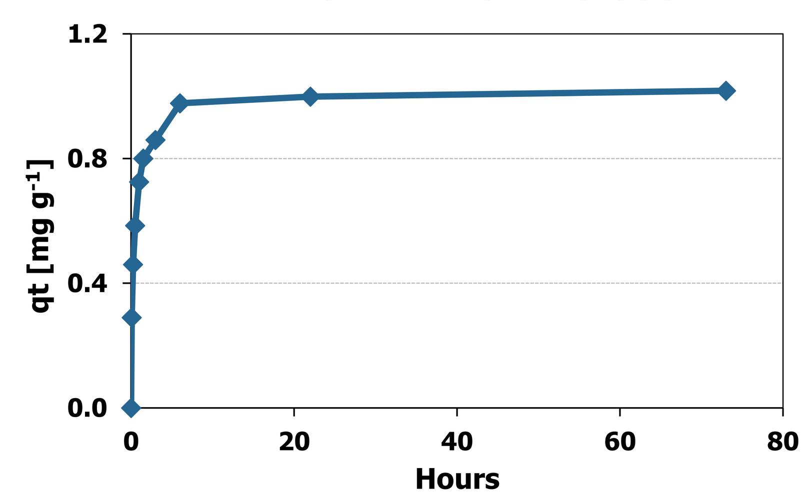


Fig. 5: Effect of contact time on nitrate adsorption capacity (q_t) of SCG-derived biochar at the optimum pH (pH 2). The adsorption capacity increased rapidly during the initial contact period and gradually approached equilibrium, reaching 1.02 mg g^{-1} after 73 h.

Conclusions

* SCG-derived biochar demonstrated the ability to adsorb both nitrate and ammonium ions, highlighting its potential as a value-added material produced from an organic solid waste stream.

* Nitrate removal was strongly influenced by pH, with maximum adsorption observed under acidic conditions (pH ≈ 2), whereas ammonium removal was favored under alkaline conditions (pH ≈ 9).

* Nitrate adsorption was significantly higher than ammonium adsorption. Nitrate removal reached 68.8% after 3 h and 81.4% after 73 h, while ammonium removal reached only 20% after 3 h.

* The higher affinity of SCG-derived biochar for nitrate may be attributed to the protonation of surface functional groups under acidic conditions, which enhances electrostatic attraction between the biochar surface and nitrate ions.

* These findings indicate that SCG-derived biochar is a promising adsorbent for nitrate removal and may contribute to sustainable nutrient management, water-quality protection, and waste valorization within a circular economy framework.

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