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Ph.D. DISSERTATION DEFENSE

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Title:	Enhanced Wastewater Treatment and Circular Economy: Utilizing Vetiver Grass (*chrysopogon zizanioides*) as a Green Technology
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ABSTRACT

Industrial munition facilities generate wastewater containing elevated concentrations of nitrogen species as a by-product of explosive manufacturing and treatment processes. Conventional treatment systems are often insufficient to handle such high-strength effluents, necessitating sustainable and scalable alternatives. This dissertation investigates a multi-stage circular economy framework that integrates phytoremediation, biomass valorization, and advanced adsorption using vetiver grass (*Chrysopogon zizanioides*) for the treatment of industrial wastewater and associated contaminants.

First, the capacity of vetiver grass to remove high concentrations of nitrate, nitrite, and ammonium was evaluated under hydroponic conditions simulating munition wastewater. Results demonstrated effective nitrogen uptake at lower concentrations, while elevated loading induced physiological stress responses including chlorosis and increased antioxidant enzyme activity, indicating threshold limitations in plant-based remediation. Building on this, a greenhouse-scale phytoremediation system was developed to optimize nitrate removal efficiency under varying plant coverage densities

(2%, 4%, and 6% w/v). A maximum removal efficiency of 75% was achieved at 6% coverage under sustained high-nitrate conditions. Associated analyses of chlorophyll content, protein levels, and enzymatic activity confirmed adaptive plant responses under prolonged nitrogen exposure.

Following phytoremediation, spent vetiver biomass was valorized through thermochemical and biochemical conversion pathways. Root biomass was converted into biochar, while shoots were processed for bioethanol production, demonstrating the feasibility of integrating waste biomass into value-added products. The produced biochar was further evaluated as a functional adsorbent for perfluorooctane sulfonate (PFOS), a persistent emerging contaminant. Batch adsorption experiments conducted under controlled pH and ionic strength conditions revealed high PFOS removal efficiency, reaching up to 85% at low influent concentrations. Surface characterization using FTIR, SEM, BET, and zeta potential analysis indicated that adsorption was governed primarily by hydrophobic interactions, pore filling, and specific surface interactions rather than electrostatic attraction. Adsorption behavior was well described by pseudo-second-order kinetics and both Langmuir and Freundlich isotherm models.

Overall, this work demonstrates an integrated and scalable phytotechnology-based system for treating nitrogen-rich wastewater while simultaneously converting residual biomass into functional materials for advanced contaminant removal. The findings advance vetiver-based remediation within a circular economy framework, linking wastewater treatment, resource recovery, and emerging contaminant mitigation in a unified environmental strategy.