Nanotechnology for Environmental Engineering (2022) 7:537–559
https://doi.org/10.1007/s41204-021-00192-3

MINI-REVIEWS

Effect of silver nanoparticles on nitrogen-cycling bacteria in constructed wetlands

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Received: 1 February 2021 / Accepted: 19 November 2021 / Published online: 1 February 2022

Abstract
Silver nanoparticles (AgNPs) are one of the most popular engineered nanomaterials (ENMs) because of their anti-microbial properties. In wastewater treatment ecosystems, ENMs can be removed by plant uptake or adsorption on biofilms. However, AgNPs can inhibit the activities of plants and microorganisms. This review outlines the effects of AgNPs on nitrogen-cycling bacteria in constructed wetlands (CWs).. Environmental conditions like organic matter, pH, ionic strength of soil along with the size, concentration, surface coating, speciation, and aggregation of AgNPs influence the toxicity. Bacterial activity is hampered by disruption of the cell membrane and extracellular polymers, reactive oxygen species (ROS) imbalance, DNA damage, inhibition of gene expression, protein functions, and energy production. Compared to heterotrophic bacteria, generally, nitrifying bacteria are more sensitive to AgNPs. Bacterial inhibition leads to a significant decrease in community diversity and reduction in nitrogen removal efficiency (NRE). Recovery of NRE is correlated with the resistance and functional redundancy of the community. Exposure to sublethal AgNP concentrations can upregulate nitrogen-cycling genes. The hormetic response and bacterial resilience are more evident in communities with high diversity. Plants enrich the diversity of nitrogen-cycling bacteria in planted CWs in the presence of AgNPs. Compared to unplanted CWs, the planted wetlands are resistant to AgNPs and consequently exhibit a better NRE after long-term exposure. Future endeavors to analyze the influence of AgNPs should be preceded by a long-term assessment of the complex interactions in actual treatment systems that are often overlooked in studies using synthetic wastewater.

Keywords Anammox · Bacterial community diversity · Denitrification · Ecotoxicology · Microbial ecology · Nitrification

Introduction

Over the last few years, the systematically designed nanoscale materials or engineered nanomaterials (ENMs) have been used for various purposes. This wide application is due to their unique attributes such as small size (1–100 nm), large surface area to volume ratio, high reactivity, high carrier capacity, high surface energy, quantum confinement, and easy variation of surface properties [1]. Silver nanoparticles (AgNPs) are one of the most frequently used ENMs. Because of their anti-microbial characteristics, they are widely used in several industries including food packaging, textile, medical devices, and health care [2, 3]. Furthermore, they have been used in catalysis, electronics, and as biosensors [4]. In the agriculture sector, AgNPs can function as plant growth stimulators, bactericides, fungicides, and insecticides [5–7]. The global manufacture of AgNPs has been projected to reach almost 800 tons by the year 2025 [8]. With increasing usage, AgNPs may be released into the environment by sewage discharge and surface runoff [9, 10]. As the last barrier in eliminating contaminants, constructed wetlands (CWs) are a sustainable, inexpensive technology for removing pollutants from wastewater. AgNP attachment to sludge biomass is one of the important processes promoting their removal [11]. As ENMs, including AgNPs from runoffs, may eventually build up in CWs, they may affect the bacterial community and consequently the bacteria-mediated nutrient removal [12–18].

CWs are dependent on the bacterial community structure for performing nitrogen removal [19]. In the nitrification–denitrification (NDN) process, chemoautotrophic nitrifying bacteria are one of the major contributors

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