


Chapter 17

Role of Nanomaterials on Soil Microbial Community and Functionality: Nanomaterial Impact – Unraveling the Dynamics of Soil Microbial Communities and Functions

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ABSTRACT

Advances in nanotechnology have transformed various fields, including agriculture. Nanomaterials (NMs) ranging in size from 1 to 100 nm are used as nanofertilizers and nanopesticides to increase agricultural yield. However, although the application of NMs has a strong effect on plant growth, it can also have an impact on the soil ecosystem and its functional properties. In addition, soil microbial communities, essential components of the soil ecosystem, perform various tasks, from forming soil structure to supporting plant growth. In this context, it becomes necessary to elucidate the role of the effects of NMs on soil microbial communities, enzymatic activities and nutrient cycling. However, some studies show

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positive effects, while others indicate negative effects on soil microbes. Therefore, selecting appropriate NMs is crucial for optimal performance in broader applications while maintaining the vitality of the soil ecosystem. This chapter focuses on the diverse impacts on soil microbial communities, enzymatic activities and nutrient cycling.

1. INTRODUCTION

Nanotechnology has experienced remarkable growth in recent decades, making significant contributions across various domains, including chemistry, physics, engineering, toxicology, agriculture, and medicine. Coined by Norio Taniguchi in 1974 to describe dimensional accuracy, the term “nanotechnology” lays the groundwork for developing functional materials, devices, and systems at the nanometer scale. Nanoparticles (NPs), ultrafine particles ranging from 1 to 100 nm in diameter, display unique phenomena that open doors to innovative applications (Rajput et al., 2021). In the realm of agriculture, nanofertilizers have emerged as a noteworthy application. Characterized by distinctive chemical features, these nanofertilizers provide a more efficient alternative to conventional chemical fertilizers. They enable effective nutrient supply to plants in controlled quantities, reducing the required dosage compared to traditional methods (Kalwani et al., 2022; Maithani et al., 2023). Additionally, they minimize nutrient losses through measures such as leaching and volatilization, while avoiding abrupt changes in chemical composition (Kalwani et al., 2022). Driven by the escalating global demand for food and the imperative to preserve soil health, agricultural researchers are increasingly delving into agri-nanotechnology. Nanoparticles find applications ranging from biosensors to eco-friendly pest protection. This encompasses the development of nanosized nutrients, bionanocomposites, nanocoated fertilizers, as well as nanobiopesticides and nano-insecticides, showcasing their versatile potential in various industries and specialized applications such as drug delivery, imaging, and substance diagnosis (Rajput et al., 2021, Upadhayay et al., 2023b). Although nanomaterials (NMs) have substantial benefits, our understanding of their potential risks to human health and the environment is still limited. Consequently, NMs are expected to enter the soil through intentional means like applying nanofertilizers or deliberate releases for remediation, as well as unintentional pathways like accidental spills during manufacturing and transportation or atmospheric emissions. It's crucial to comprehend the detailed interactions between NMs and the soil environment because it has significant implications for both human health and ecological well-being (Nogueira et al., 2012). However, the consequences of using NMs are debatable. While some studies support the positive influence of NMs, highlighting their ability to enhance soil microbial communities and reflective functions like soil enzymatic activities (Liu et al., 2021; Sutariya et al., 2023 et al., 2023; Wijesooriya et al., 2023), others present adverse effects on soil microbial communities (Shen et al., 2015; Simonin et al., 2018; Khan et al., 2021). In soil ecosystems, microbes play crucial roles in various functions, from soil formation to nutrient cycling, and supporting plant growth in the rhizosphere by engaging in activities such as nitrogen fixation, nutrient solubilization, disease suppression, and abiotic stress mitigation (Upadhayay et al., 2023b, 2023c). The influence of NMs on soil microbial communities is complex and influenced by factors such as organic matter content, soil mineral type, the type, size, and dose of NMs, exposure duration, soil types, and environmental conditions, all of which impact soil microbial diversity and associated functional attributes (Ge et al., 2011, Pawlett et al., 2013; Khati et al., 2017; Khan et al., 2021; Kalwani et al., 2022; He et al., 2023). As we navigate through the intricate landscape of nanotechnology, it is imperative to consider regulations, challenges, and strategies for responsible

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