

# ROLE OF NANOPARTICLES IN PERTURBATION OF SOIL MICROBIAL COMMUNITIES

## Abstract

Agriculture faces numerous challenges such as the reduce in crop yield, a decrease in the organic content of soil as well as nutrient deficiencies. Conventional fertilizers are applied to address these issues, but their nutrient release often does not align with the plant's needs, resulting in low nutrient use efficiency [1, 2]. Nanotechnology offers a promising solution through the development of nanoparticles (NPs) and nanodevices for agricultural applications. Nanofertilizers are materials that releases nutrients in a regulated manner, leading to a higher crop growth and reduced nutrient loss compared to chemical fertilizers [3]. However, the introduction of NPs into soil raises concerns about their impact on microbial communities and soil properties. NPs can interact positively and negatively with plants and rhizospheric communities, affecting soil properties and the environment [4, 5]. The presence of NPs in soil can lead to hazardous environmental effects and may alter soil microflora through toxicities or changes in toxin bioavailability. Microbial communities take up a critical role in agricultural productivity, and understanding the impact of NPs on beneficial bacteria is crucial. NPs can induce ROS production, leading to cell damage and microbial biomass reduction [6]. Comprehensive technology, public awareness, and integrated legislation are essential for regulating NPs and preventing their toxicity [7]. In conclusion, although NPs offer significant agricultural improvements, their potential adverse effects on the microbial communities and the environment should be considered. Implementing sustainable soil management practices and evaluating NP fate through modern approaches can help minimize

## Authors

### **Pooja Tamuk**

Soil Science and Agricultural Chemistry  
ICAR-IARI  
New Delhi, India.  
tamukpooja09@gmail.com

### **Babetlang Kharshiing**

Environment Science  
ICAR-IARI  
New Delhi, India.  
babetlangkharshiing@gmail.com

### **Jayanti Yomso**

Agronomy  
LPU, Punjab  
India.  
Jayantiamiyomso@gmail.com

environmental damage and promote responsible nanofertilizer use in agriculture.

**Keywords:** Microbial communities, nanoparticles, nanofertilizer, agriculture, sustainability

## I. INTRODUCTION

Agriculture faces various challenges globally which includes a reduction in crop yield, diminishing absorption of nutrients, a decrease in organic content of soil and multi-nutrient deficiencies. To address these deficiencies, fertilizers are supplemented to enhance crop production and fulfill the plant's nutrient requirements. However, nutrient release from fertilizers should align along with the plant's needs. Unfortunately, the actual quantity of nutrients reaching the crop's target site is often insufficient due to factors like leaching, hydrolysis, photolysis, decomposition, insolubility in soil, or immobilization by microorganisms [2]. It resulted in low efficiency, as evident from the low nutrient use efficiency (NUE) of nitrogen, phosphorus, and potassium, as NUE values for these macronutrients are approximately 30-35%, 18-20%, and 35-40%, respectively [1]. Consequently, a significant portion of applied fertilizers remains inaccessible [2].

Nanotechnology can be explored as a new source of key improvements in the agricultural sector as it enables the development of nanodevices and nanoparticles (NPs) for applications in agriculture and plant biotechnology [8]. NPs release nutrients in a controlled manner, reducing loss and improving crop growth and requires in lower nutrient quantities as compared to chemical fertilizers [3]. Slow-release nano-fertilizers increase grain yield and minimize nutrient leaching. Nano urea-hydroxyapatite (HA) binds strongly to urea, extending release time by ~12 times while releasing nitrogen over 60 days, while commercial fertilizers do so in four days [9]. Nanofertilizers enhance plant biomass, yield, and essential amino acid production [3]. However, the application of NPs has raised concerns against microbial communities. Nanoparticles can have positive as well as negative associations with the plants and also with the rhizospheric communities. It can hamper soil properties as well as cause hazardous effects on the environment [4, 5]. It can cause massive hindrances towards soil microflora by altering the bioavailability of toxins or through toxicities [8, 10].

Soil microorganisms take up a crucial role in agricultural productivity by recycling elements, organic matter decomposition and directly promoting crop growth through various mechanisms. They can indirectly promote plant growth by suppressing plant pathogens and also can be used as soil inoculants to boost agricultural production. Therefore, understanding the impact of carefully engineered nanoparticles on these beneficial bacteria is essential [4,5]. The impact of nanoparticles on soil microorganisms as well as other environmental niches needs further investigation, considering their wide range of applications. Changes in bacterial community structure indicate that nanoparticles can potentially modify microbiomes in the soil. However, the specific effects are influenced by nanoparticle composition, emphasizing the need to assess the environmental impacts of different nanoparticle formulations. Therefore, it is crucial to understand how NPs affect crop performance and to evaluate the diversity in soil bacterial communities when exposed to specific metal oxide nanoparticles. This chapter provides an insight into the fate and behaviour of NPs within the soil.

## II. SOURCE OF NANOPARTICLES IN AGRICULTURE

NPs are ubiquitous entities and can originate from natural or human sources. NPs in the atmosphere are called ultrafine particles, NPs in soil and water are colloids with varying sizes. Naturally occurring NPs have been present since the earth's formation and are found significantly in the oceans, atmosphere, water, soil, and living organisms. Comparing the

ecosystems of soil, water, and air, the soil ecosystem is believed to acquire the highest levels of NPs, including the engineered ones introduced through sewage and faulty agricultural practices [10]. It is critical to understand the impact of NPs on soil enzymatic activities and on the environment.

In agriculture, nanofertilizers are a significant source of NPs, offering a promising approach to enhancing productivity. Nanotechnology has the potential to genetically improve plants and drugs at the cellular level while increasing the efficiency of conventional fertilizers [3]. Nanofertilizers with their large surface area can release nutrients slowly, matching crop requirements and improving nutrient uptake efficiency by threefold [11], thereby reducing water pollution [3]. Zinc oxide and silver NPs they have been reported to show exhibit anti-phytopathogenic activity, enhance seed germination, and promote plant growth. With zinc-deficient soils in India, nanoparticulate zinc formulations can be utilized [12].

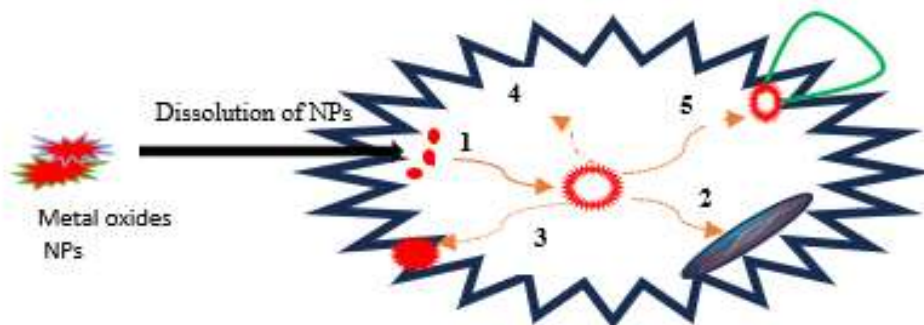
NPs can potentially impact the soil physicochemical properties and microbial metabolic activities in the soil rhizosphere. However, the small size and mobility of NPs (10 nm) can lead to unintended cellular effects and potential toxicity when taken up by soil organisms [4]. The form and concentration of NPs play a crucial role in determining their transport, bioavailability, toxicity, and ecological impact. Hence, examining the role of nanoscale contaminants is important in current and future pollution scenarios in soil and aquatic ecosystems [5, 13]. NPs can significantly impede soil microflora through direct toxicity or by altering toxin bioavailability, and they can also indirectly disrupt the organic compound synthesis and create antagonistic interactions. Various factors such as physicochemistry, concentration, time, and growth medium, influence the impact of NPs on microbial communities [8, 10].

### III. EFFECT OF NANOPARTICLES ON SOIL MICROBE

When NPs are applied to soil, they can persist in sediment for an extended period, and their interaction with soil and metal ion release is influenced by soil properties and the aging process [5]. NPs can be dissolved in the water present in the soil, resulting in increased bioavailability and uptake of the released metal ions. The dissolution of NPs is influenced by factors such as soil type, texture, physicochemical properties, and mode of application. Consequently, the soil microbiome is exposed to emerging contaminants like metal-engineered nanoparticles, which can affect enzymes and microorganisms involved in soil processes. Enzymes and microorganisms involved in soil processes can be affected by NPs, leading to reduced microbial activity [8, 9].

Application of zero-valent NPs (nZVI) with straw amendment has been found to reduce microbial biomass, indicating bactericidal effects on microbial functional groups [14]. Oxidation of nZVI can result in reactive oxygen species [ROS] production in living cells, leading to membrane disruption, leakage of intracellular materials, and impairment of biochemical processes, ultimately causing cell death [Figure 1]. The accumulation of ROS due to NPs can reduce crop productivity by affecting seed germination and root elongation, potentially posing risks to human health [6, 8]. Nanomaterials such as CuO and Fe<sub>3</sub>O<sub>4</sub> have been shown to alter soil microbial populations and their toxicity is related to their solubility and bioavailability [15]. The presence of ZnO NPs has been found to decrease extractable soil DNA and the activities of soil protease, catalase, and peroxidase [16]. The application of

single-walled carbon nanotubes (SWCNTs) in soil has been shown to decrease the activities of various enzymes involved in organic matter degradation, potentially due to the generation of ROS and physical damage to microbial cells [8, 17]. C60 fullerenes have been found to reduce the number of fast-growing bacteria in the soil, while microbial biomass and respiration were unaffected [18]



1. NOS Production
2. Damage DNA
3. Disruption of membrane
4. Affect translocation and transformation process
5. Interruption of ETS

**Figure 1:** The possible ways of Damaging the Bacterial Cell by NPs.

Studies have shown that the introduction of CuO NPs in water-logged paddy soils caused a decrease in soil microbial biomass, and ZnO, TiO<sub>2</sub>, CeO<sub>2</sub>, and Fe<sub>3</sub>O<sub>4</sub> NPs have been found to alter soil bacteria and nitrogen fixation processes [19]. ZnO and CeO<sub>2</sub> NPs can decrease the abundance of specific bacteria involved in phosphorus and potassium solubilization, as well as negatively affecting their enzyme activities [19]. The toxic effects of ZnO NPs on the ammonification process in soil have been observed, with time-dependent and dose-dependent responses, particularly in acidic soils [20]. Additionally, concentration levels of NPs play a crucial role in the interactions at the microbial level. It has been postulated that the NPs-toxicity on soil microbes is directly proportional to their low concentration levels as evaluated on tomato and maize plant interactions, on mycorrhizal fungi in response to the application of ZnO NPs [21].

#### IV. MITIGATION APPROACHES FOR NP-TOXICITY IN THE ENVIRONMENT

It is important to understand the NP toxicity within the ecosystem. Due to the inadequacy of monitoring and detection devices, NP interaction with the environment was not properly studied. With the advancement of technology, NP interaction in the environment has become the focal point of study. The use of various biomarkers has served as the most important biological assessment tool. The idea of permeable-ion barriers has been formulated as a tool to arrest NPs [22]. A complete form of comprehensive and advanced technology that constitutes public awareness and integrated legislation is a proactive and substantial approach to synchronize the intricacy of NPs to prevent their toxicity [7]. It is also pertinent to develop various regulatory actions, environmental testing and monitoring to provide validated results

for consideration of ecotoxicology of NP in the environment [23]. Hence, these assessments are needed to regulate along with contemporary approaches to produce accurate results to avoid NP-mediated environmental damage.

The toxicity of NPs in the ecosystem is complex, but advancements in detection and monitoring tools have shed light on their fate in the environment. Biomarkers and permeability barriers are valuable for tracking and containing NPs [22]. Comprehensive technology, public awareness, and integrated legislation are proactive approaches to regulating NPs and preventing their toxicity [7]. Regulatory actions, environmental testing, and monitoring are necessary for the accurate assessment of ecotoxicology and NP fate [23]. These contemporary approaches are essential to mitigate NP-induced environmental damage.

## V. CONCLUSIONS

NPs have the potential to stimulate crop growth and control pollution, but they also pose a serious threat to the rhizospheric populations and the environment as a whole due to their accumulation potential. It is crucial to gather valuable information about NPs and their impact on biological interactions in the soil due to their dual action. The extensive production and persistence of nano-products in the soil ecosystem have disrupted beneficial microflora and soil components. The unique properties of NPs, such as surface charges, size, area, and reactivity, hinder positive interactions among soil, plants, and microbes. The proliferation of NPs in the soil can negatively affect microflora, leading to toxicity, accumulation, and resistance mechanisms. To address these challenges, it is crucial to gather valuable information about NPs and their impact on the soil ecosystem. Regulatory actions, environmental testing, and monitoring are essential for accurately assessing the ecotoxicology and fate of NPs. By implementing contemporary approaches, we can mitigate the potential environmental damage caused by NPs and safeguard the long-term health of our ecosystems. It is crucial to prioritize sustainable practices and responsible use of NPs to strike a balance between their benefits and potential risks.

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