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Interaction between Nanoparticles and Soil Microflora

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ABSTRACT
This report presents a literature review on the interaction of nanoparticles with soil microbial communities. This article discuss how nanoparticles affect different types of microorganisms present in the soil. They affect their microbial diversity, size and enzymatic activities. Organic and Inorganic nanoparticles have different type of impact on soil microflora. Also, the concentration, environment and time of exposure determines the impact of nanoparticles on the microflora.

KEYWORDS: Nanoparticles * Microbial * Inorganic NPs * Organic NPs * Concentration

1. INTRODUCTION

According to United Nations, World population is expected to reach 9.7 Billion by the end of 2050 (UN Dept.). As the constant increase in population, the need for more food has also raised. These needs cannot be full filled by traditional crop system for a longer time. With the concern of providing food to such huge population, there has to be a new technology giving more yield in short period.

Nanotechnology is an emerging field in biology, chemistry, physics and other disciplines. It is manipulation of a matter on an atomic, molecular and supramolecular scale to create materials or devices with vastly different properties (Wikipedia, Nanotechnology). Nanomaterial/ Nanoparticle is defined as a particle of matter that is between 1 and 100 nanometres (nm) in diameter. Nanoparticles (NPs) have many potentials applications in agriculture to enhance crop productivity and improve soil health by enriching soil microbial communities. The soil microbiota and plants are among the major coreceptors of NPs. The microflora of soil is collection of various types of microorganisms. They play important role in maintaining the fertility of soil, decomposing the waste organic matter, cycling the nutrients and help in plant growth. These microflorae are broadly classified into bacteria, actinomycetes, fungi, algae and protozoa. In the soil, when these nanoparticles can interact with

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microorganisms, they might facilitate their absorption rate. When the NPs enter the soil, they can undergo physical, chemical and/or biological changes depending on their nature and on their interactions with various soil components (organic and inorganic). In this way, they can also affect the microbial structure, diversity and their enzymatic activities in soil (Simonet and Valcárcel, 2009).

There are various examples of different nanoparticles having an impact on microflora of soil. Fullerene is a third form of carbon along with graphite and diamond that features unique properties (Taylor and Walton, 1993). They are hollow sphere or tubular composed entirely of carbon atoms. They are ideally used as photo-resists, organic photovoltaics, spin-on carbon hard masks and organic photo detectors. The two most common fullerenes are C_{60} and C_{70}. Due to such unique properties, they are used as nanomaterials to supply nutrients to various plants and microflora of the soil. Carbon nanotubes (CNTs) are cylindrical molecules that consist of rolled-up sheets of single-layer carbon atoms (graphene). They can be single-walled (SWCNT) with a diameter of less than 1 nanometre (nm) or multi-walled (MWCNT), consisting of several concentrically interlinked nanotubes, with diameters reaching more than 100 nm (N. Saifuddin et al, 2013). CNTs have high strength, low density, strong hydrophobicity and strong stealth. These properties make them one of the most important nanomaterials at present. Copper nanoparticles are a type of metal nanomaterial. They display unique characteristics such as catalytic and antifungal or antibacterial activities which are not observed in copper metal (Wikipedia, Copper Nanoparticle). Because of their small size, they can achieve higher reaction yield and shorter reaction time (Dhas et. Al, 1998).Zinc is an essential trace element for human system without which many enzymes such as carbonic anhydrase, carboxypeptidase, and alcohol dehydrogenase become inactive. It is essential for eukaryotes because it modulates many physiological functions (Jansen et. al, 2009, Maremanda et. Al, 2014). Zinc oxide nanoparticle is one such inorganic metal oxide which can safely be used as medicine, preservative in packaging, and an antimicrobial agent (Baum et. al, 2000, Hiller et. al, 1971).

This review will enlighten about the impacts and possible threats posed by Nanoparticles on microbial community and how the microbial diversity, size, and their activities in soil are affected through nanomaterials.

1.1. SOILMICROFLORA Definition

Soil consist of both Biotic and Abiotic components. Microflora is the biotic component of soil. It covers about 1-5% of soil. Essential roles played by the microflora is to maintain the fertility of soil, decompose the waste organic matter, cycle the nutrients and help in plant growth. These microflorae are broadly classified into bacteria, actinomycetes, fungi, algae and protozoa. They inhabitant in rhizosphere zone. It is the area around a plant root.

1.2. Examples

Microorganisms help in various functions. Such as enriching the soil, cycling the nutrients to the plant for their adequate growth, etc. They can be either in symbiotic relationship with plant root or be

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independent in the soil. Given below are few of the examples of microflorae:N Fixing Bacteria - Nitrogen is the major component of Chlorophyll which helps in photosynthesis. Azotobacter, Azospirillum, etc. help in fixing atmospheric Nitrogen into fixed nitrogen (usable form). Thus, play a vital role in Nitrogen cycle. They can be in symbiotic or non-symbiotic relationship with the host plant.Fungi - A symbiotic relation between a plant and a fungus is called Mycorrhizal association. Fungus help in uptake of Nitrogen, Phosphorous and Potassium, Sulphur and some micronutrients to the plants and plants supplies carbohydrate to the fungus through the process of Photosynthesis. Examples are Orchid Mycorrhiza, Arbuscular Mycorrhiza, Ectotrophic Mycorrhiza, etc.

2. NANOPARTICLES

2.1. Definition

A nanoparticle is usually defined as a particle of matter that is between 1 and 100 nanometres (nm) in diameter (Wikipedia, Nanotechnology).

2.2. Properties of Nanoparticles

Nanoparticles have unique properties due to which they are easily transported to the soil, plants and microbes of the soil. The following are the few unique properties observed in Nanomaterials.

2.2.1. They have high surface area to volume ratio. They have relatively larger surface area when compared to the same volume of material made up of bigger particles. It means that the surface area to volume increases as the radius of the sphere decreases. Therefore, they get easily absorbed by the plants.

2.2.2. They are highly soluble. Therefore, they can improve the solubility and dispersion of insoluble nutrients in soil through coating around it.

2.2.3. Due to their small size, they are highly specific in targeting.

2.2.4. They are can released in controlled manner by encapsulating them in envelopes made up of semipermeable membrane such as resin-polymer, wax, etc.

2.2.5. They are also highly mobile and easy to trace (P. Solanki et al. 2015, Sasson et al. 2007).

3. EXAMPLES OF NANOPARTICLES WITH SOIL MICROBIAL COMMUTNITIES

It is observed that microorganisms can either be directly affected by the nanoparticles or indirectly by amplifying the bioavailability of other toxic compounds already present in the soil. This impact of nanoparticles on microbial diversity and their activity is highly dependent on the type of nanoparticles used. It can be either inorganic (metal or metal oxides) or organic (fullerenes or carbon nanotubes) nanoparticles. It is observed that inorganic nanoparticles have higher toxic potential than organic ones. Below mentioned are few of the examples on how organic and inorganic nanoparticles affect microbial diversity and it's functioning.

3.1. Fullerenes

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In a study, Fullerene C_{60} (1 mg kg^{-1} soil in aq. Suspension or 100 mg kg^{-1} soil in granular form) was given to slit clay loamy soil in microcosms for 180 days. There was no effect on soil respiration, enzymatic activities, PLFA profiles or DGGE profiles (Tong et al., 2007). In another study, Fullerene C_{60} was given to Sandy clay loamy soil in different concentrations (0, 5, 25, 50 mg kg^{-1} soil) in microcosms for 0, 7, 14 days. There was no effect of fullerene on soil respiration, microbial biomass, and on the enumeration of protozoans. The decrease in bacterial enumeration was only seen immediately after contamination. There were limited effects on DGGE profiles for both bacteria and protozoans (Johansen et al., 2008). Fullerenes nanoparticles can promote the production of crops, which may cause crops to absorb more nutrients such as inorganic salts and organic matter from the soil, thereby limiting the survival of soil microorganisms (Monica and Cremonini, 2014). The mechanism of the toxicity of fullerene to microorganisms could block the electron transfer between microbial cells because of its high electron affinity leading to cell death (Lyon et al., 2007). Fullerenes also disrupt the normal secretion of enzymes in microbial cells, causing the cells to lose balance in metabolism (Chen et al., 2017c).

3.2. Carbon nanotubes (CNTs)

Carbon nanotubes (CNTs) are cylindrical molecules that consist of rolled-up sheets of single-layer carbon atoms (graphene). They can be single-walled (SWCNT) with a diameter of less than 1 nanometre (nm) or multi-walled (MWCNT), consisting of several concentrically interlinked nanotubes, with diameters reaching more than 100 nm (N. Saifuddin et al, 2013).

3.2.1. MWCNTs

In another study, different amounts (0, 0.1, 100, or 1000 mg/kg) of MWCNTs were added to the agricultural topsoil (0–20 cm depth), and it was observed that in the vegetative stage of plants, microbial communities could only be affected when the content of MWCNTs in the soil was extremely low, which was manifested in an increase in the number of bacteria (Ge et al., 2018).

In a study, MWCNTs were given to two types of sandy soil at different concentrations (50, 500, 5000 mg kg-1 soil) in microcosms for 0, 1, 4, 11 days. In both the soils, most enzyme activities decreased at 500 mg kg-1 soil, and all enzymatic activities as well as microbial biomass C and N were significantly lowered at 5000 mg kg-1 soil (Chung et al., 2011). It is also found that direct contact between MWCNTs and microbial cells could cause damage to microbial cell walls or cell membranes, results in a large loss of intracellular substances such as DNA and RNA (Kang et al., 2008). MWCNTs entering the cells could also promote the cells to produce more reactive oxygen species, causing different degrees of damage to DNA, proteins and other substances in the cells (Chen et al., 2018; Jia et al., 2005; Shvedova et al., 2012).

3.2.2. SWCNTs

Liu et al. (2009) observed the effects of pure SWCNTs on Escherichia coli, Staphylococcus aureus and Bacillus subtilis, and concluded that SWCNTs mainly enter the microbial cells through physical puncture to destroy the cell structure. Zhou et al. (2013) found that the degree of influence of SWCNTs on microbial

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communities was closely related to the content of SWCNTs through studying the microorganisms in paddy soils with SWCNTs. When the content of SWCNTs was extremely high, the microbial activity and enzyme activity in the soil will decrease greatly. When the content of SWCNTs was very low, the microbial community in the soil did not change obviously compared to soil without SWCNTs. In a study, SWCNTs was given to sandy loam soil at different concentrations (0, 30, 100, 300, 600 and 1000 mg SWCNT kg^{-1} soil) in microcosms for 25 days. High concentrations of SWCNTs significantly altered soil microbial community composition. Gram-positive and Gram-negative bacterial and fungal biomass decreased with higher SWCNT concentrations (Jin et al., 2014). The main toxicity mechanism of SWCNTs to microorganisms is oxidative stress. SWCNTs can induce a large amount of reactive oxygen species in cells, thereby damaging cell membranes and various substances in cells (Chen et al., 2018; Jia et al., 2005; Shvedova et al., 2012) In microorganisms with nucleus, SWCNTs can enter the nucleus and alter the structure of nucleic acids, inhibiting DNA transcription, which can have varying degrees of impact on microorganisms (Chen et al., 2013; Ong et al.,2016).

3.3. Copper Nanoparticles (CuNPs)

The toxic effect of Cu-based NPs has been shown for beneficial soil microbes such as nitrifying bacteria, nitrogen-fixing bacteria, Arbuscular mycorrhiza and other Rhizobacteria; however, it also influences other microorganisms. In a study by Shi et al. (2018), it was found that higher concentrations of CuO nanoparticles can result in decreased SOM contents in paddy soils. Nanoparticles of CuO had no effect on total SOM, except changes in biochemical composition (Ben-Moshe et al., 2013). CuO-NPs induced morphological and genetic alterations in leaf litter decomposing fungus which could impact organic matter decomposition rate (Pradhan et al. 2011). After two years of study, it was observed that a low concentration of nCuO (10 mg kg^{-1}) showed a positive impact on microbial population and enzymatic activity (Jośko et al., 2019). Cu -NPs have Copper ions which can be toxic to beneficial as well as pathogenic bacteria (Lofts et al. 2013). The bacteria from Sphingomonas genus and Rhizobiales known for their importance in remediation and symbiotic nitrogen fixation appeared susceptible to Cu-NPs (Shah et al. 2016). In a study, it was shown that CuO-NPs were very toxic for native soil bacteria, as the formation of cavities, holes, membrane degradation, blebs, cellular collapse, and lysis in the cells of soil bacterial isolates were observed (Concha-Guerrero et. al., 2014).

3.4. Zinc Nanoparticles (ZnNPs)

After two years of study, it was observed that a low concentration of

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nZnO (10 mg kg−1) showed a positive impact on microbial population and enzymatic activity (Jośko et al., 2019). Nano-sized ZnO caused reduction in microbial biomass carbon (MBC) (Ben-Moshe et al., 2013; Rajput et al., 2018; Rashid et al., 2017b). In another study, different doses of nanoparticles of ZnO were given to soil in microcosms for 60 days. It was concluded that NMs reduced MBC and had negative impact on substrate induced respirations, showing reduced microbial activity (Ge et al., 2011). After 9 months of incubation in lysimeters, ZnO-NPs (45 mg soil) reduced protease, catalase, and peroxidase activities in soil (Du et al. 2011). In another study by Rousk et al. (2012), two soils i.e. Mineral soil and organic soil were given ZnO NPs in microcosms for 5-7 h of incubation. NP ZnO reduced bacterial growth in both the soils.

CONCLUSION

After studying about various types of interaction between nanoparticles and microflora of soil we can conclude that nanoparticles might be advantageous or disadvantageous to the microflora. They might increase the microbial population and its enzymatic activities (eg; nCuO) or decrease their population due to higher concentrations of nanoparticles (eg; SWCNTs). The impact also depends upon concentration, environment and time of exposure of nanoparticles. For future research, we can promote development of sustainable nano-enabled agriculture in which smart nanoparticles will be developed. These nanoparticles would be able to sense the requirement of given microbial community and act accordingly. In this way, the negative impact of nanoparticles on microbial communities could be removed efficiently.

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