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Review Article

Effect of nano-fertilizers on soil microflora

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Abstract: Nano fertilizers are one of the recent advancement tools in agriculture that are developed with an aim to increase nutrient use efficiency, reduce wastage of fertilizers and indirectly the cost of cultivation. Besides this they improve the growth and yield of crop and the quality parameters. Nano-fertilizers are very effective for precise nutrient management in precision agriculture with matching the crop growth stage for nutrient and may provide nutrient throughout the crop growth period. However, it has also been speculated that nano-fertilizers can increase the crop growth up to certain optimum concentrations, further increase in concentration may cause nutrient toxicity thereby inhibiting the crop growth. It is also necessary to assess the effect of slow release nano-fertilizer on the soil enzyme activity and soil microbial population. The introduction of nano-fertilizers into the natural environment may pose threat to beneficial microbial communities. The impact of nano-fertilizers on microbial activity could be determined through measurement of soil respiration and enzymatic activities. This review would therefore focus on the effect of nano-fertilizers on the activity of soil microorganisms including both their beneficial and deleterious effects.

Keywords: Nano-fertilizers; Soil Microflora; Fertility; Nutrient management; Precision agriculture

Introduction

Nano-fertilizer technology is quite innovative and the literature in this field is very scanty. Nanotechnology in agriculture has gained momentum in the last decade with an abundance of public funding, but the pace of development is modest, even though many disciplines come under the umbrella of agriculture (De Rosa *et al.,* 2010). Nanotechnology posses the potential to augment agricultural productivity through genetic improvement of plants and animals along with cellular level delivery of genes and drug molecules to specific sites in plants and animals (Scott, 2007; Maysinger, 2007). The potential is increasing with suitable techniques and sensors being identified for precision agriculture, natural resource management, early detection of pathogens and contaminants in food products, efficient delivery systems for agrochemicals such as fertilizers and pesticides, improved systems integration for food processing, packaging and other areas like monitoring agricultural and food system security (Preetha and Balakrishnan, 2017; De Rosa *et al.*, 2010).

Nutrient use efficiencies of conventional fertilezers hardly exceed 30-35%, 18-20% and 35-40% for N, P and K fertilizers respectively. The data remain constant for the past several decade and research efforts did not yield fruitful results. Nano particles have extensive surface area and capable of holding abundance of nutrients and release it slowly and steadily such that it faciletates uptake of nutrients matching the crop requirement without any associated ill-effects of customized fertilizer inputs. Nano-fertilizers provide more surface area for different metabolic reactions in the plant which increase rate of photosynthesis and produce more dry matter

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and yield of the crop. It also prevents plant from different biotic and abiotic stress conditions and increases the nutrient use efficiency by three times (Preetha and Balakrishnan, 2017, Duhan *et al.,* 2017). Nano fertilizers increase biosource use and are ecofriendly in nature. It improves carbon uptake and improves soil aggregation. Nano fertilizers can also be designed to encapsulate nutrients and growth promoters to ensure a slow and a targeted efficient release (Manjunatha *et al.,* 2016). Integrating nanotechnology in agriculture is still in its infancy but several products are already commercialized such as copper based (Cu) nano-pesticides used as a fungicide and bactericide (Dikshit *et al.,* 2013).

Previous ecotoxicological studies raised concerns about the impact of nanomaterials on plant health and soil organisms (McKee and Filser, 2016; Tripathi *et al.,* 2017) and even food quality and soil fertility (Chen *et al.,* 2015; Judy *et al.,* 2015). However, most studies were performed under simplified laboratory conditions (e.g., soil microcosms or hydroponics), at unrealisticcally high concentrations, or used pristine nano particles that are not comparable to comercial nano-enabled products (Simonin and Richaume, 2015; Chen *et al.,* 2017). Furthermore, several parameters deserve to be investigated in more depth, such as plant–microbial interactions, fluctuating environmental conditions, physio-logical acclimation and evolutionary adaptations to repeated exposures, or interactive effects with other stressors that may be strong drivers of the environmental fate and ecotoxicity of nano-agrochemicals (McKee and Filser, 2016). As the production and release of these novel nano-formulations in agro-ecosystems may increase in the future, developing realistic long-term environmental assessments of nano-agrochemical impacts is imperative. A variety of literature is available that shows the positive correlation of nano-fertilizers on the plant growth and enhancement of seed germination but there is very little work reported on the effect of soil microflora by the application of nano-fertilizers in soil. Today, information about the impact of nano-fertilizers on the soil microbiome are still rare, although microbial communities are important and sensitive targets for determining the environmental hazards of nanoparticles (Holden *et al.,* 2014). Few studies have shown significant negative effects on soil microbial biomass (−38.0%), bacterial ammonia oxidizers (−17.0%), and the *β-Proteobacteria* population (−14.2%) after 1-year exposure to 0.01 mg AgNP/kg in a loamy soil, while *Acidobacteria* (44.0%), *Actinobacteria* (21.1 %) and *Bacteroidetes* (14.6%) were significantly stimulated (Grün *et al.,* 2018; Grün and Emmerling, 2018). Therefore, a detrimental disturbance on soil ecosystem functions, such as nitrification, organic carbon transformation and chitin degradation could be assumed.

Nano fertilizers

Fertilizers are indispensable in agricultural production system. The fertilizer application has exponentially increased from 0.5 million tonnes in 1960 to 28 million tonnes in 2012 that helped the country to increase the grain output from just 51 million tonnes to 255 million tonnes during the same period (Manjunatha *et al.,* 2016). Despite fertilizer application remarkably increased the grain growth; the yields of several crops got plateaued due to the low fertilizer response ratio, imbalanced fertilization, low organic matter, increased intensities of multi-micro-nutrient deficiencies across the country. (Morales-Díaz *et al.,* 2017). Within the set of challenges faced by the soil scientists, imbalanced fertilization is one of the most critical factors to be considered for nitrogen management.

Nanotechnology has potential to develop slow release efficient fertilizers (Komarneni, 2009).

As we are all aware that clays are the key factor in deciding the soil fertility due to the fact that the surface area is huge and its adsorptive sites assists in retention and release of nutrients. For instance, one gram of montmorillonite can be spread to a dimension of 30-40 m^2 (Macht *et al.,* 2011), if the same clay reduced by ball milling process and its dimension got reduced to nanometers that increase the surface area by several fold of 750m^2g^{-1} (Rahale, 2010).

Nano-fertilizers and nano-composites can be used to control the release of nutrients (De Rosa *et al.,* 2010) from the fertilizer granules so as to improve the nutrient use efficiency while preventing the fixation or loss of nutrients to the environment (Subramanian and Tarafdar, 2009) and supply with range of nutrients in desirable proportions (Datta, 2011). Zeolite and nano-porous zeolite is used as a slow release fertilizer in farming (Ramesh *et al.,* 2010). Zeolite incorporated urea, potassium sulphate and calcium hydroxyapatite as a slow release nano-fertilizer increased availability for 60 days (Kottegoda *et al.,* 2011).

Nano-fertilizer formulations have a potential to increase nutrient use efficiencies under the greenhouse conditions (Subramanian and Rahale, 2010). While these nano formulations that can also be in the form of nano-pesticides, may protect the crops from fungal and bacterial diseases, it may have unintended consequences on non-target plant associated microorganisms involved in plant nutrition, such as mycorrhizal communities or nitrogen fixing bacteria (Hussain *et al.,* 2009). Moreover, beneficial soil microorganisms that degrade organic matter (OM), which maintain long-term soil fertility, may be sensitive to this broad-spectrum anti-microbial product (Bünemann *et al.,* 2006; Lejon *et al.,* 2008). If so, these nano-formulation applications might have undesirable consequences for soil fertility and plant yields over the long term, especially as a result of repeated exposures. Increasing exposure to engineered inorganic nanoparticles takes place in both terrestrial and aquatic ecosystems worldwide. Although we already know some harmful effects of nanoparticles on the soil bacterial community, information about the impact of the factors functionalization, concentration, exposure time, and soil texture on the nanoparticle effect expression are still rare (Grun *et al.,* 2019).

Effect of nano-fertilization on soil microorganism

Some researchers are working on the studies related to the effect of nano-fertilizers on the viability and susceptibility of soil microflora. One of the studies (Rajput *et al.,* 2018) has showed that nano-fertilization increased soil nutrients, improved soil ecological environment, and increased soil microbial quantity. Besides the number of soil microorganisms treated with nano-fertilizer was significantly higher than that treated with chemical fertilizer. Nano-fertilizer produces large amounts of humic acid during slow release. Humic acid is the core of soil fertility and provides carbon and nitrogen sources for soil microorganisms (VandeVoort and Arai, 2019). In addition, humic acid can directly or indirectly improve soil temperature, moisture and gas permeability, regulate soil pH, promote soil microbial growth and reproduction, and increase its quantity and variety (Subramanian and Tarafdar, 2009).

In another study on the effect of nanoparticles on soil microorganisms and crops in liquid cultures, the researchers were able to show that titanium oxide (TiO_2), at elevated concentrations, can disturb the symbiosis between clover and bacteria and have a negative impact on the growth of clover (Morales-Díaz *et al.,* 2017). In natural soil, the mobility of the nanoparticles was weak and no increase in the uptake of titanium dioxide by the plants was found.

Although the mobility of multi-walled carbon nanotubes (MWCNT) in soils was also weak, the experiments showed a concentration-independent uptake of MWCNT by the plants and a reduction in the number of red clover blossoms in the case of high concentrations. Both TiO_2 and MWCNT in very high concentrations resulted in a change in the composition of the microbial communities that interact with the plants (National Research Programme, 2019).

In yet another study on green pepper plant, application of slow-release nano-fertilizer significantly increased soil enzyme activity and soil microbial population. Compared with blank, soil dehydrogenase and catalase activities of nano-fertilizer treatment increased by 37.4% and 21.3%, respectively, and soil bacteria, actinomycetes and fungi increased by 50%, 72% and 208%, respectively (Nibin *et al.*, 2019). The application of slow-release nano-fertilizer can improve soil nutrient, soil enzyme activity and soil microorganism, and also reduced nutrient loss and improved soil ecological environment, with a good application value (Rajput *et al.*, 2018; Teng *et al.*, 2018).

In another research, investigation was conducted to study the effect of soil and foliar application of organic nano NPK formulations on microbial load (bacteria and fungi) and their role in improving the enzymatic activities (dehydrogenase, acid phosphatase, alkaline phosphatase and urease) of the experimental soil. Fertilizer samples were analyzed and particle size of granular organic nano NPK and liquid organic nano NPK were 89.26 nm and 67.30 nm respectively (Nibin *et al.*, 2019). The soil samples were collected at the final harvest of the crop for calculating the microbial load and enzymatic activities of the soil. From the result it was indicated that amongst the different treatment combinations, application of farm yard manure (FYM) (12 T. ha^{-1}) plus soil application of nano NPK (12.5 kg. ha^{-1}) and foliar application of nano NPK (0.4%) recorded the highest bacterial count, dehydrogenase, urease and acid phosphatase content in the post-harvest status of the soil (Nibin *et al.*, 2019).

Contrary to the above findings, in a recent study the effects of metallic copper nanoparticles (CuNPs) as a nano-fertilizer on the soil nitrification process were evaluated. One of the primary drivers for investigating the use of nanoscale copper was to increase micronutrient delivery and uptake efficacy without causing the negative impact on the soil nutrient cycles While CuNPs sorb strongly to soils, they showed negative effects on nitrification kinetics between 1 and 100 mg/L. The dissolution of Cu^{2+} as well as potential reactive oxygen species (ROS) production could explain the suppressed nitrification kinetic rate. The window of [Cu^{2+} (aq)] for beneficial effects as a constituent in soil nitrifier seems very small. These results suggested that the delivery of Cu-incorporated nano-fertilizer must be carefully evaluated with respect to its trace metal toxicity to microorganisms in various agricultural soils (VandeVoort & Arai, 2019).

In yet another study, (Rajput *et al.*, 2018) the possible threats posed by toxicity of various nanoparticles on plants and microbial diversity was explored. It was found that the exposure of soil to nanoparticles caused a decrease in soil microbial biomass and enzymatic activity, which impacts microbial community composition including yeasts, bacteria, fungi, and biological diversity. The effects of nanoparticles on plants result in various types of abnormalities. Nanoparticles can also pose risks to human health. It was concluded that increased applications of nanoparticles can pose a threat to beneficial microbial communities as well as crops and soils. Thus, it is important to explore whether nanoparticles could compromise crop yield, soil properties, soil organisms, and functional activities of soil (Rajput *et al.,* 2018).

According to the study conducted by Xu *et al.,* (2015), TiO_2 and CuO nanoparticles decreased soil microbial biomass and enzymatic activities, affected on their community structures in flooded paddy soil. Similar results were obtainned by You *et al.,* (2018), who studied the effect of ZnO, TiO_2, CeO_2, and Fe_3O_4 nanoparticles on soil enzymatic activities (invertase, urease, catalase, and phosphatase) and bacterial communities of saline-alkali and black soils. The results showed influence on soil enzyme activities and changes in soil bacterial community and threat on biological nitrogen fixation.

Zinc oxide (ZnO) and CeO_2 nanoparticles affect-ted the plate counts of *Azotobacter*, phosphorus-solubilizing and potassium-solubilizing bacteria and inhibit enzymatic activities (Chai *et al.,* 2015).

Results obtained by Jiling *et al.,* (2016) have shown that a high concentration of Fe_3O_4 nanoparticles significantly decreased the content of bacteria in soil. Titanium dioxide nano-particles reduced the abundance of functional soil bacteria and enzymatic activity and posed detrimental effect on microbial activity, abundance and diversity (Buzea *et al.,* 2007; Solanki *et al.,* 2008).

The data obtained by Maliszewska (2016) demonstrated that the biogenic Au nano-particles up to the concentration of 33 mg/kg do not affect the soil processes and can be classified as not harmful. However, antibacterial activities (growth inhibition zone) were observed on clinical isolates (*Bacillus subtilis, Escherichia coli, Klebsiella pneumoniae, Pseudomonas aeruginosa, Salmonella typhi*, and *Staphylococcus aureus*) treated with ZnO nanoparticles synthesized by biological and chemical methods (Lakshmi *et al.,* 2012). Little is explored on the effect of CuO nano-particles on the soil microbial community. Inorganic nanoparticles seem to have a greater toxic threat than organic nanoparticles on soil microorganisms (Frenk *et al.,* 2013).

Concha-Guerrero *et al.,* (2014) have shown that CuO nanoparticles were very toxic for native soil bacteria, as the authors observed formation of cavities, holes, membrane degradation, blebs, cellular collapse and lysis in the cell of soil bacterial isolates.

Pradhan *et al.,* (2011) investigated the effect of CuO and Ag nanoparticles on leaf microbial decomposition showing that exposure to these nanoparticles led to a decrease in leaf decomposition rate.

In another research, (Simonin *et al.*, 2018) the effect on plant and microbial responses to repeated $Cu(OH)_2$ nano-pesticide exposures were studied under different fertilization levels in an agro-ecosystem. The investigators examined the effects of repeated realistic exposures of the $Cu(OH)_2$ nano-pesticide, Kocide 3000, on simulated agricultural pastureland in an outdoor mesocosm experiment over 1 year (Simonin *et al.,* 2018). The Kocide applications were performed alongside three different mineral fertilezation levels (Ambient, Low, and High) to assess the environmental impacts of this nano-pesticide under low-input or conventional farming scenarios. The effects of Kocide over time were monitored on forage biomass, plant mineral nutrient content, plant-associated non-target microorganisms (i.e., N-fixing bacteria or mycorrhizal fungi) and six soil microbial enzyme activities. We observed that three sequential Kocide applications had no negative effects on forage biomass, root mycorrhizal colonization or soil nitrogen fixation rates. In the low and high fertilization treatments, the investigators observed a significant increase in aboveground plant biomass after the second Kocide exposure (+14% and +27%, respect-tively). Soil microbial enzyme activities were significantly reduced in the short-term after the first exposure (day 15) in the ambient (−28% to −82%) and low fertilezation (−25% to −47%) but not in the high fertilization treatment. However, 2 months later, enzyme activities were similar across treatments and were either unresponsive or responded positively to subsequent Kocide additions. There appeared to be some long-term effects of Kocide exposure, as 6 months after the last Kocide exposure (day 365), both β-glucosidase (−57 % in ambient and −40% in high fertilization) and phosphatase activities (−47% in ambient fertilization) were significantly reduced in the mesocosms exposed to the nano-pesticide. These results suggest that when used in conventional farming with high fertilization rates, Kocide applications did not lead to marked adverse effects on forage biomass production and key plant–microorganism interactions over a growing season. However, in the context of low-input organic farming for which this nano-pesticide is approved, Kocide applications may have some unintended detrimental effects on microbially mediated soil processes involved in carbon and phosphorus cycling (Simonin *et al.,* 2018).

In another study, (Grun *et al.,* 2019) three soils of different grain size were exposed for up to 90 days to bear and functionalized silver nano particles (AgNP) in concentrations ranging from 0.01 to 1.00 mg/kg soil dry weight. Their effects on soil microbial community were quantified by various biological parameters, including 16S rRNA gene, photometric, and fluorescence analyses. Multivariate data analysis revealed significant effects of AgNP exposure for all factors and factor combinations investigated. For the biological parameters assessed in this study, the matching of soil texture and silver species, and the matching of soil texture and exposure time were the two most relevant factor combinations. The factor AgNP concentration contributed to a lower extent to the effect expression compared to silver species, exposure time and physico–chemical composition of soil. The factors functionalization, concentration, exposure time, and soil texture significantly impacted the effect expression of AgNP on the soil microbial community. Especially long-term exposure scenarios are strongly needed for the reliable environmental impact assessment of AgNP exposure in various soil types (Grun *et al.,* 2019).

Effect of Nanoparticles on Soil Diversity

Soil is predicted to be the largest recipient of nanoparticles (NPs). Artificial introduction of NPs into the soil might have significant impact, as they may be extremely resistant to degradation and have the potential to accumulate in the soil. According to Ben-Moshe *et al.,* (2013) NPs appear to affect many microscopic properties of the soil. The protection of soil microbial biomass and diversity is one of the major issues in the field of sustainable use of soils (Torsvik and Ovreas 2002). The effect of NPs on the soil depends on their concentration, soil type, and enzymatic activity of soil. At high concentrations of NPs, the negative effect on dehydrogenase activity was observed by Josko *et al.,* (2014). Another adverse effect caused by NPs is the influence on the rate of soil self-cleaning as well as on the balance of nutrients, which is the basis for the regulation of the processes of plant nutrition and soil fertility improvement (Janvier *et al.,* 2007; Suresh *et al.,* 2013). Considering the presence of NPs in soil, it is imperative to study their influence on soil biodiversity (Bondarenko *et al.,* 2013).

Soil properties play a key role in the toxic effect of NPs. Soil properties, such as pH, texture, structure, and organic matter content, influence the soil microbial community and the ability of pollutants to have toxic effects on microorganisms (bioavailability) (Simonin and Richaume 2015). Nanoparticles could affect mobility of soil pollutants. Therefore, there is a need to compare the toxicity of the NPs in various types of soils. The soil amended with digestate and fly ash reduced the pollutant bioavailability (Garcia-Sanchez *et al.,* 2015). Another study suggests that particle size distribution and the composition of the organic matter altered microbial populations in the contaminated soils (Calvarro *et al.,* 2014).

Intentional influence on soil properties and composition by amending the soil with various substances can also alter the effects of NPs. Biochar is a soil amendment used for increasing soil fertility and productivity. Servin *et al.,* (2017) show minimal effects of CeO_2 NPs on plants in biochar-amended soil. However, the studies on the interaction between NPs and biochar-amended soil are not well researched (Rajput *et al.,* 2018).

Nanoparticles as Antagonists to Plant Pathogens

In some studies, silver nanoparticles have been used to get rid of harmful microorganisms in plants. Biological synthesis of silver nanoparticles in sizes ranging from 6 to 38 nm from white radish (*Raphanus sativus* var. *aegyptiacus*) has been documented. The exposure of the snails and soil matrix to silver nanoparticles in a laboratory experiment reduced the activity and the viability of the land snail (20% of silver nanoparticles treated snails died) as well as the frequency of fungal population in the surrounding soil (Ali *et al.,* 2015).

Spherical shaped silver nanoparticles in size range of ~10 to 20 nm using culture supernatant of *Serratia* sp. BHU-S4 and their effective application for the management of spot blotch disease in wheat have been experimented. Silver nanoparticles exhibited strong antifungal activity against *Bipolaris sorokiniana*, the spot blotch pathogen of wheat (Mishra *et al.,* 2014).

Effect of silver nanoparticles with diameters of 20 nm on seeds of Fenugreek (*Trigonella foenum-graecum*) has been carried out (Hojjat, 2015). Different concentrations of silver nanoparticles (0, 10, 20, 30 and 40 μgmL^{-1}) were used and results showed that maximum seed germination (76.11%), speed of germination (4.102), root length (76.94 mm), root fresh weight (2.783) and root dry weight (1.204) at a concentration of 10 $\mu g\ mL^{-1}$. These results revealed that application of silver nanoparticles could be used to significantly enhance seed germination potential, mean germination time, seed germination index, seed vigor index, seedling fresh weight and dry weight.

In a study by Elumalai *et al., (*2015), Zinc oxide (ZnO) nanoparticles have been tested in the laboratory as bactericide and fungicide. ZnO nanoparticles using leaf extract of *Moringa oleifera* in size range from 16 to 20 nm has been synthesized and antimicrobial activity against bacterial strains such as *Staphylococcus aureus*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Proteus mirabilis*, *Escherichia coli* and fungal strains such as *Candida albicans* and *Candida tropicalis* using the agar disc diffusion method has been tested. The maximum zone of inhibition was observed in *Staphylococcus aureus* (23.8 ± 0.76) as compareed to others.

Spherical and hexagonal zinc oxide nano particles from *Parthenium hysterophorus* have been synthesized by inexpensive, ecofriendly and simple method using different concentrations of 50% and 25% of *Parthenium* leaf extracts with size 27 ± 5 and 84 ± 2 nm, respectively. These zinc oxide nanoparticles were explored for the size-dependent antifungal activity against plant fungal pathogens i.e. *Aspergillus flavus* and *Aspergillus niger*. A maximum zone of inhibition was observed for 27 ± 5 nm size zinc oxide nanoparticles against *Aspergillus flavus* and *Aspergillus niger*. *Parthenium* mediated zinc oxide nanoparticles proved to be good anti fungal agents and environment friendly (Rajiv *et al.,* 2013).

In a study by Bhumi and Savithramma (2014), Spherical shaped ZnO nanoparticles with an average size of 23 to 57 nm were prepared by zinc acetate and NaOH using leaves of *Catharanthus roseus* leaf extracts. The synthesized zinc oxide nanoparticles were evaluated for antibac - terial activity against Gram negative bacteria (*Escherichia coli* / ATCC 25922; *Pseudomonas aeruginosa* / ATCC 15442) and Gram positive bacteria (*Staphylococcus aureus* / ATCC 65 38; *Bacillus thuringiensis* / ATCC 10792). *B. thuringiensis* indicated the resistance to zinc oxide nanoparticles followed by *E. coli* whereas *P. aeruginosa* was more susceptible. This study concluded that ZnO nanoparticles might be used as anti - bacterial formulations against *P. aeruginosa*

Nano-biofertilizers as Plant Growth Promoters

The use of silver and gold nanoparticles as a growth promoting materials has also been studied and were found to be effective (Dikshit *et al.,* 2013). These nanoparticles with natural bio fertilizers such as *Pseudomonas fluorescens*, *Bacillus subtilis* and *Paenibacillus elgii* have shown very good growth promotion under *in vitro* conditions. Hence, they are required in very minute quantities in comparison to other fertilizers and their costs are manageable as one liter of nano-biofertilizers can be used in several hectares of crops. Several soil microorganisms are present in the rhizosphere zone, especially plant growth promoting rhizobacteria (PGPR) have the best plant growth-promoting activeties. The impact of gold nanoparticles on PGPR was investigated viz., *Pseudomonas fluorescens*, *Bacillus subtilis*, *Paenibacillus elgii* and *Pseudomonas putida*. No positive or negative impact was observed in *P. putida* to gold nanoparticles. Significant increase was observed in case of *P. fluorescens*, *P. elgii* and *B. subtilis* and hence gold nanoparticles can be exploited as nano-bio-fertilizers (Shukla *et al.,* 2015).

Properties of Nano-Fertilizers for Higher Nutrient Use Efficiency (NUE)

It is now well known that nano-fertilizers have higher surface area due to very less size of particles which provide more sites to facilitate different metabolic process in the plant system resulting in the production of more photosynthates. Due to higher surface area and very less size they have high reactivity with other compounds, high solubility in different solvent such as water. Particle size of nano-fertilizers is less than 100 nm which facilitates more penetration of nano-particles into the plant from applied surface such as soil or leaves and leads to more penetration and uptake of the nutrient (Singh *et al.,* 2017), thereby helps to increase the nutritional quality parameters of the plant (such as protein, oil and sugar content) by enhancing the rate of reaction or synthesis process in the plant system. Application of zinc and iron on the plant increases total carbohydrate, starch, Indole acetic acid (IAA), chlorophyll and protein content in the grain (Rajaie and Ziaeyan, 2009). Nano-ferric oxide increase photosynthesis and growth of the peanut plant (Liu *et al.,* 2010).

Fertilizers encapsulated in nano-particles will increase availability and uptake of nutrient to the crop plants (Tarafdar *et al.,* 2012). Zeolite based nano-fertilizers are capable to release nutrient slowly to the crop plant which increase availability of nutrient to the crop though out the growth period which prevent loss of nutrient from denitrification, volatilization, leaching and fixation in the soil especially nitrate-nitrogen (NO_3-N) and Ammonium-nitrogen (NH_4-N). Particle size below 100 nm nano-particles can be used as a fertilizer for efficient nutrient management which are more eco-friendly and reduce environment pollution (Liu *et al.*, 2010).

Recently, Indian agro-scientists have developed world's first nano-fertilizer through biosynthesis. The newly developed nano-fertilizer has the ability to bring down the use of chemical fertilizers by 80-100 times, thus saving considerable foreign exchange in import of fertilizers. The new variant of fertilizer was developed by Dr. J.C Tarafdar at Central Arid Zone Research Institute under Indian Agriculture Research Institute (IARI). The fertilizer was prepared by developing a methodology to use microbial enzymes for breakdown of the respective salts into nano-form. The newly developed fertilizer is 2-4 times less expensive compared to chem.-ical fertilizers. It increases Nutrient Use Efficiency (NUE) by three-fold and 10 times more stress tolerant. Since it is complete bio-source, nano-fertilizer is eco-friendly and improves soil aggregation, moisture retention and carbon build-up. There is no health hazard and is suitable for all crop varieties including food grains, vegetables and horticulture. The Nutrient Use Efficiency (NUE) of nano-fertilizer is 58-51%, while it is 15-16% for both SSP (Single Super Phosphate) and Diammonium phosphate (DAP) (Rahale, 2010).

Nano-fertilizers are more beneficial as compared to chemical fertilizers as there is three-times increase in Nutrient Use Efficiency (NUE); 80-100 times less requirement to chemical fertilezers; develops 10 times more stress tolerant by the crops; it is complete biosource, so eco-friendly and there is around 30% more nutrient mobilization by the plants; there is about 17-54% improvement in the crop yield and; improvement in other properties such as soil aggregation, moisture retention and carbon build up (Singh *et al.*, 2017).

The yield per hectare is also much higher than conventional fertilizers, thus giving higher returns to the farmers. Thus balanced fertilization to the crop plant may be achieved through nanotechnology.

Fate of Nano-fertilizers on Ecosystems

The nano fertilizers used for plants could be transferred from crop fields to the soil, water and atmosphere by contaminated leachate, run-off by rain, transport by wind or trophic transfer (by harvested organs or in the agricultural waste incorporated into the soil or used for compost). Use of NFs should be subjected to careful analysis, considering that their acidental presence in products for domestic animal or human consumption is a poorly documented subject. Various studies on the subject indicate that nanoparticles are absorbed by microorganisms in the soil, the sediment and the roots of plants. They are transported from the roots to other organs of the plant where they accumulate. Transfer to the next trophic level occurs when the microorganisms, plant structures or their waste are consumed by protozoa, fish, arthropods, annelids, molluscs, insects, and possibly birds and mammals, demonstrating that the negative effects are even manifestted in their progeny. This phenomenon has also been demonstrated in marine organisms and confirmed to occur in other plant-herbivore-carnivore food chains (Morales-Díaz *et al.*, 2017; Torsvik and Øvreas, 2002; Morales-Diaz *et al.*, 2017; Simonin *et al.*, 2018).

Conclusion

Nano-fertilizers received tremendous attention due to their unique properties and beneficiary applications in agriculture system. From the above discussion it was observed that although nano-fertilizers are the slow release efficient fertilizers and they improve the nutrient use efficiency while preventing the fixation or loss of nutrients to the environment and supply with range of nutrients in desirable proportions. They also protect the crops from fungal and bacterial diseases, but they may have unintended consequences on non-target plant associated microorganisms involved in plant nutriation, such as mycorrhizal communities or nitrogen fixing bacteria. Moreover, beneficial soil microorganisms that degrade organic matter, which maintain long-term soil fertility, may be sensitive to this broad-spectrum antimicrobial product. If so, these nano-formulation applications might have undesirable consequences for soil fertility and plant yields over the long term, especially as a result of repeated exposures. Although we already know some harmful effects of nanoparticles on the soil bacterial community, information about the impact of the factors functionalization, concentration, exposure time, and soil texture on the nanoparticle effect expression are still rare. There are mixed results on the effect of nano-fertilization on soil microorganism where in one study the number of soil microorganisms treated with nano-fertilizer was significantly higher and in another study the researchers were able to show that nano fertilizers, at elevated concentrations, can disturb the symbiosis between plant and bacteria and have a negative impact on the growth of plants. Potential risk and consequences in the environment are difficult to quantify and are poorly understood. Thus the conclusion of the above study is that more research is further required to optimize the doses of nano-fertilizers use so that they can augment plant growth without any detrimental effect on soil microflora.

Moreover, as the behavior of nanoparticles differs significantly in laboratory conditions and the natural environment, there is a need to increase the knowledge on final fate and effect of nanoparticles in every different type of agriculture soil and appropriate guidelines are required to be framed to avoid contamination. The increasing number of results discussing toxicity of nanoparticles requires to be considered. Proper assessment and guidelines will be helpful for the future direction of nanotechnology research and its applications, so that it does not become a menace for ecosystem health.

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