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Nano-fertilizer -Way towards Efficient Crop Nutrition

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Abstract

Nano fertilizers have emerged as a potential solution to the challenges associated with traditional synthetic fertilizers in agriculture. Nano-fertilizer offers advancements in crop management systems by improving nutrient delivery and reducing the reliance on synthetic fertilizers. They can be categorized as nanoscale fertilizers, nanoscale additive fertilizers, or nanoscale coating fertilizers, depending on their composition and mode of action. Nanomaterials encapsulate nutrients and enable slow and efficient nutrient release, resulting in balanced nutrition throughout the plant's growth cycle. Nano fertilizers offer advantages such as increased crop yield, enhanced nutrient availability, and reduced adverse environmental impact. However, careful monitoring and advance research are necessary to address limitations and ensure safe and effective use. Future studies should focus on evaluating the safety and toxicity of nanomaterials, understanding their interaction with different soil types, exploring bio-synthesized nanoparticle-based fertilizers, and assessing their impact on the environment and human health.

1. Introduction

Modern day agricultural production and productivity largely depends upon the use of fertilizers, but injudicious use of nutrient supplying materials irreversibly damages the balance of soil ecosystem. Therefore, minimum and efficient use of fertilizers and agrochemicals are inevitable for maintaining the sustainability of agriculture. Advancement in the nano-engineering techniques (nanotechnology) paved the way to overcome excessive use of agrochemicals by developing an improved crop management system that assures sustainability. Nanomaterials has the capacity to efficiently control the supply of nutrients to the plant system, thus minimize the loss of mineral nutrients. In present day crop management, fertilizers are applied directly into the soil or sprayed on the plant canopy, which often exceed the plant nutrient demand at a particular time. Hence, a large part of the applied nutrients lost

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due to evaporation, drift, leaching, hydrolysis, run-off, and photolytic or microbial action. This excess amount of chemical fertilizer adversely affects the nutrient balance of the soil as well as soil ecosystem and causes contamination of local water bodies.

2. What is Nano Fertilizer?

Worldwide, agricultural practices are changing rapidly after the introduction of green nanotechnology. Nano-fertilizers, which can be used in specific concentrations considering the nutrient requirement of the crop leads to reduction of losses. There are commonly three types of nano fertilizers- nanoscale fertilizers, nanoscale additive fertilizers, and nanoscale coating fertilizers (Mastronardi et al., 2015). Nanoscale fertilizers represent a ground breaking advancement in agricultural practices, offering innovative approaches to nutrient delivery and improving crop performance. These fertilizers consist of nanoparticles with dimeters below 100 nm, which are designed to contain and deliver essential nutrients to plants effectively. They provide several distinct advantages over traditional fertilizers, including enhanced nutrient utilization efficiency, reduced environmental impact, and targeted nutrient delivery. In the case of nanoscale additive fertilizers, the incorporation of nanoscale additives into traditional fertilizers offers an opportunity to enhance their effectiveness. These additives can modify the physicochemical properties of the fertilizers, such as solubility and dispersion, leading to improved nutrient availability and uptake by plants. By utilizing nanoscale coatings on traditional fertilizers, nanoscale-coating fertilizers provide a protective layer that enhances nutrient retention and controls nutrient release, leading to more efficient and sustainable nutrient utilization. The encapsulation of nutrients within nanomaterials is a widely used technique for producing nano-fertilizers. This process involves enclosing the nutrients in nano-porous materials, coating them with a thin polymer film, or incorporating them into emulsions of nanoscale dimensions. These encapsulation strategies offer several advantages, such as controlled and sustained release of nutrients, protection against leaching and volatilization, and improved nutrient stability. Moreover, the encapsulation of beneficial microorganisms, including nitrogen-fixing bacteria and mycorrhizal fungi, within nanostructures has shown promise in enhancing nutrient availability, particularly nitrogen, phosphorus, and potassium, in the root zone. This symbiotic relationship between microorganisms and nano-fertilizers can promote plant growth, improve soil fertility, and reduce the reliance on synthetic fertilizers.

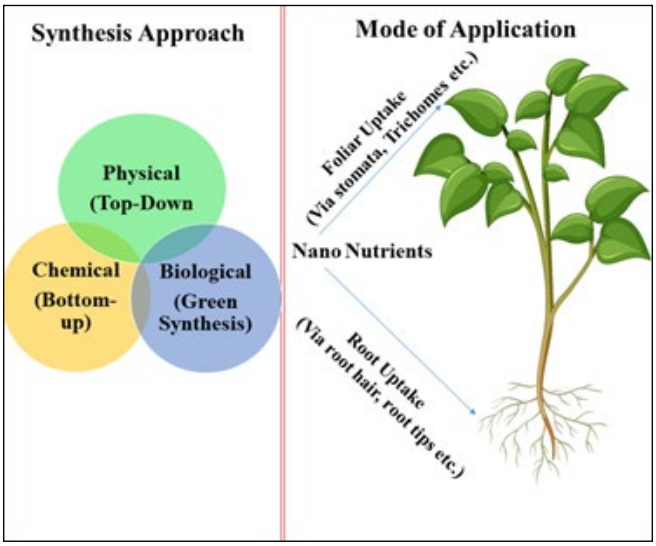

Figure 1: Synthesis approaches and mode of application of nano-fertilizers

To produce the nanomaterials used in nano-fertilizers, both physical (top-down) and chemical (bottom-up) approaches are employed. Physical methods involve reducing the size of bulk materials through processes such as grinding, milling, or high-energy ball milling. Chemical methods, on the other hand, involve the synthesis of nanoparticles through chemical reactions and the controlled growth of nanostructures. These manufacturing techniques enable the development of nanomaterials with specific properties and tailored characteristics to optimize nutrient delivery and maximize their effectiveness in agricultural applications. Nano-fertilizers can also be distinguished based on their actions such as control or slow-release fertilizers; nanocomposite fertilizers (using a nanodevice for supplying different macronutrient and micronutrients in required concentration).

As nano-fertilizers continue to evolve, researchers are exploring novel strategies, such as the use of nano-porous materials, thin polymer films, and emulsions, to enhance their performance further. Additionally, the potential of nano-fertilizers to improve nutrient availability and crop productivity is being investigated through field trials and long-term studies.

3. Advantage and Limitation of Nano-fertilizers

Nano-fertilizers can improve productivity by increasing nutrient availability in soil and nutrient uptake by plants. Planned use of nano-fertilizers may reduce the ecological concern created by the blanket use of conventional fertilizers. It has been reported that nano fertilizers can improve crop productivity by improving seed germination, boosting seedling growth and photosynthetic activity of plants (Das and Beegum, 2022). Nanomaterials enters the plant body through root and leaf surface, which are highly porous at the nanoscale. Nutrient uptake by plant may be enhanced after nano fertilizer application through these pores, or the process can facilitate forming complex with molecular transporters or root exudates through creation of new pores, or using endocytosis or ion channels (Mastronardi et al., 2015).

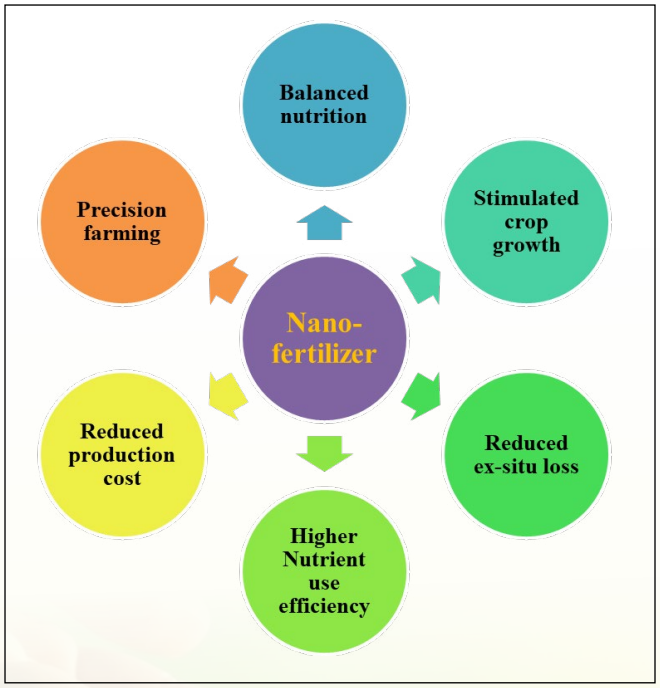

Figure 2: Major advantages of nano-fertilizers

Decreased size of nanomaterials results in increase in the surface mass ratio of particles which enables the absorption of abundant nutrient ions that is later desorbed slowly for an extended period. Therefore, formulations of nano fertilizers can provide balanced nutrition for crops throughout the growth period of crop and improves yield.

Due to high sorption capacity, increased surface to volume/mass ratio, and controlled-release mechanism to targeted sites; nanomaterials become a potential plant growth enhancer. Because of these characteristic features, nano-fertilizers can be used as a smart delivery system of nutrients to crop plant. Nano-fertilizers release nutrients very slowly in comparison to conventional fertilizers which results in increasing the nutrient-use efficiency and decreasing nutrient loss. In a nut shell, nano-formulation of fertilizers increased nutrient use efficiency by extending fertilizer release period which results into reduced the usage of chemical fertilizers, increase in crop yield by facilitating nutrient mobilization and reduced soil toxicity as very low quantity with reduced frequency of application.

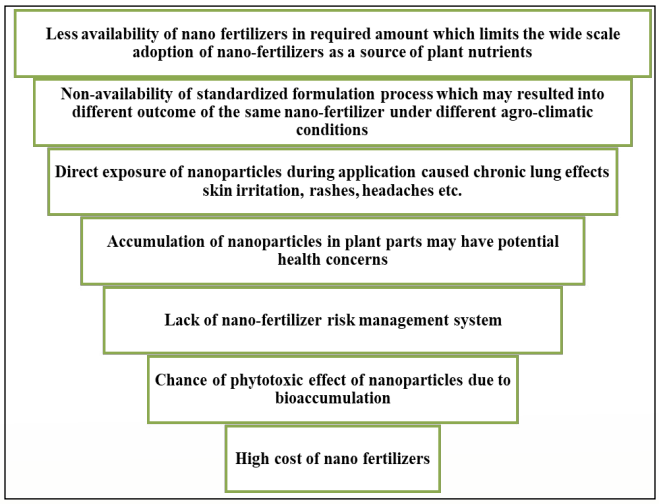

Figure 3: Drawbacks associated with the use of nano-fertilizers

Despite aiding in sustainable crop production, limitations of nano-fertilizers should be carefully considered before use and marketing. The limitations of using nano-fertilizers mainly arise due to the absence of rigorous monitoring and research gaps.

4. Nano-fertilizers in India

Nano formulation of urea commercially came in Indian market during middle of 2021, to be used as an alternative to conventional urea. Nano urea contains 4% N in nano nitrogen form of size range (20–50 nm) dispersed in water. Due of its better efficiency, nano-urea can cut down the amount of traditional urea required. The product is recommended for all crops and soils. Nano-Urea has been assessed for biosafety and toxicity in accordance with the criteria of Department of Biotechnology of Government of India, and international guidelines. Nano urea is non-toxic and harmless for the user; nevertheless,

while spraying on crops, it is advisable to use a face mask and gloves. Keep out of the reach of children and pets and store in a dry area away from extreme temperatures.

Recently, nano liquid DAP (di-ammonium phosphate) fertiliser has been approved in India for use in farmers field after nano-urea. Nano-DAP is a unique foliar formulation that supplies nano Nitrogen (8%) and Phosphorus (16%) to crops. Application of nano DAP reduces the requirement of conventional DAP and other phosphatic fertilizers while decreasing input cost.

5. Future Prospects

Future studies must be focused on generating comprehensive knowledge in safety and toxicity of different nanoparticles used for nano-fertilizer production and application. Effect of nano-fertilizers in different soils is necessary in order to understand the specificity of nano-fertilizer for a specific crop and soil type. Biosynthesized nanoparticle-based fertilizers and nano-biofertilizers should be explored further as a promising technology in order to improve yields while achieving sustainability. The following possible aspects may also be explored -

- Accumulation of nanoparticle in edible parts of crops and bioavailability of the accumulated nanoparticles to the next trophic level.
- Physiological mechanism of uptake and translocation by plants
- Influence of nanoparticles in rhizosphere and on root surface
- Determining possible interactions of nano-fertilizers with the biotic or abiotic environment and their possible amplified bioaccumulation effects
- Effect on environment and human health

6. Conclusion

The effect of nano-fertilizers lies in the high surface to volume ratio which increases its absorption and reaction. Nano-fertilizers have opened new opportunities to improve inputs use efficiency, minimize costs and environmental footprints. Therefore, the scope for application of nano-fertilizers in agricultural system needs to be prioritized. Moreover, it is essential to ensure the safe and responsible use of nano-fertilizers, including rigorous monitoring of their environmental impact, potential nanoparticle release, and their effects on soil microbial communities and human health.

7. References

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