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Review on Nanotechnology in Organic Fertilizers: A Sustainable Agricultural Revolution

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Review article

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ABSTRACT

Nanotechnology has emerged as a promising frontier in agriculture, offering innovative solutions to enhance the efficiency and sustainability of organic fertilizers. Organic farming practices, known for their environmental benefits and reduced chemical inputs, often face challenges in nutrient delivery and crop yield optimization. The global agricultural industry faces increasing challenges in feeding a growing population while minimizing environmental impacts. In this context, nanotechnology has emerged as a transformative tool in the development of organic fertilizers. This abstract provides a concise overview of the application of nanotechnology in organic fertilizers, highlighting its potential to revolutionize sustainable agriculture. However, the utilization of nanotechnology in organic fertilizers also raises concerns regarding potential environmental and health risks associated with nanoparticles. Careful research, regulation, and risk assessment before approval of any nanotechnology-based agri-product. This includes evaluating the toxicity of the nanomaterials

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used, the potential for environmental release, and the impact on human health are essential to ensure the safe and responsible application of nanomaterial's in agriculture.

Keywords: Nanotechnology; nanoparticles; nutrient delivery.

1. INTRODUCTION

Nanotechnology has brought about groundbreaking advancements in various fields, including agriculture [1]. One significant application is the integration of nanotechnology into organic fertilizers, revolutionizing the way we enhance crop productivity while minimizing environmental impacts. This introduction explores the fusion of nanotechnology and organic fertilizers, highlighting its potential benefits and challenges.

"Agriculture is always an important sector for developing countries. The main purpose of using fertilizer in agriculture gives full-fledged macro and micronutrients, which usually lack in soil. The fertilizers play a vital role in increasing agricultural production, where 35 – 40 % of crop productivity depends upon fertilizer" [2]. "Nano fertilizers can be produced by adding nutrients individually or in combination to the adsorbents with nano-dimensions. In the case of cationic nutrients, the target nutrients are loaded as is, whereas the anionic nutrients are loaded after surface adjustment to create the nanomaterials using physical and chemical methods" [3]. "A new technology involves the encapsulation of fertilizers within NPs, which can be accomplished in one of the following three ways: the nutrient can be provided as nanoscale particles or emulsions; it can be coated with a thin polymer layer; or it can be enclosed within Nano porous materials" [4]. "Controlling matter at 1–100 nm dimensions for use in measurements, creating models for virtual forecasts, and manipulating the nanoscale matter are all included in the definition of a Nano fertilizer" [5]. "The excessive use of chemical fertilizers negatively damages the chemical systems of soil and limited the available place or area for crop production. Therefore the farmers focus on the development of fertilizers system for plants. Nanotechnology is the smarter way to overcome all these drawbacks from the agriculture system. Nanotechnology is a range of technologies related to the development of matter at a length scale of 1-100nm (Nanotechnology encompasses the production and application of physical, chemical, and biological systems at scales ranging from individual atoms or molecules to around 100 nanometers, as well as the integration of the resulting nanostructures into larger systems)" [2]. "Particles which are less than 100 nm are seen as atoms or molecules and at the end corresponding bulk material, which can lead to dramatic modifications in the physicochemical properties of the material. The importance of nanoparticles may be due to, a greater density in reactive surface areas on the particles. Therefore, with the use of nanoparticles and nano-powders, researchers can produce controlled or delayed release fertilizer [6].

"The consolidation of nanotechnology in fertilizer products may improve release profiles and increase uptake efficiency, leading to significant economic and environmental benefits. Scientists have identified that the nano-size particles of fertilizer will improve crop production while maintaining the chemical ecology of soil. Nano-fertilizer involves the employment of nanoparticles in agriculture to provide the beneficial effect of plant growth or crop production" [7]. The biosynthesis nano fertilizer was innovated by Indian agro- scientist

This paper will also discuss the effect of nano-scale fertilizer on crop production, growth, and nutrition, also the pros and cons of nano-fertilizers risk and limitations.

2. NANO FERTILIZERS

Nano fertilizers are a specific application of nanotechnology in agriculture, where nanoparticles are used to enhance the efficiency and effectiveness of fertilizers. These tiny particles, typically measuring less than 100 nanometers in size [8], offer several advantages when incorporated into fertilizers, potentially revolutionizing modern agriculture [9, 10]. Here's an overview of nano fertilizers Fig.1:

2.1 Enhanced Nutrient Delivery

Nano fertilizers are designed to carry and release essential nutrients (such as nitrogen, phosphorus, and potassium) more efficiently to plants. These nanoparticles can encapsulate nutrients, protecting them from environmental

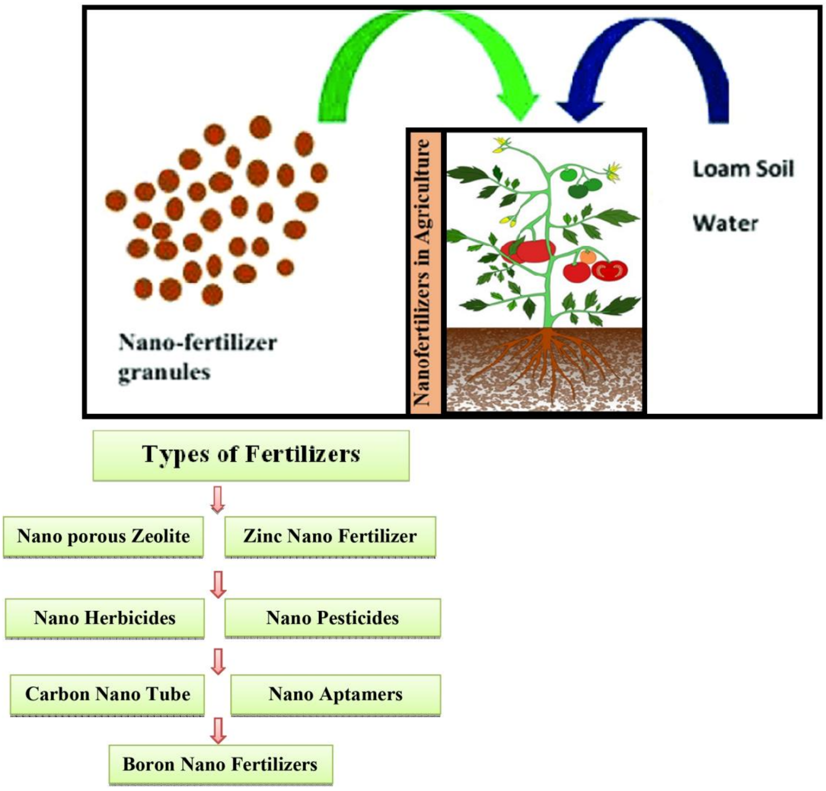

Fig. 1. Schematic representation of different types of nanomaterials used as nano-fertilizers and their effects in agriculture

factors like leaching or volatilization [11]. This controlled release ensures that plants receive nutrients in a gradual and targeted manner, promoting better nutrient uptake and reducing fertilizer wastage.

2.2 Improved Nutrient Use Efficiency

Traditional fertilizers can often result in nutrient loss due to factors like runoff and soil fixation [12]. Nano fertilizers address these issues by reducing nutrient loss (Decreases fertilizers loss due to runoff and leaching), ensuring that a higher percentage of applied nutrients reach the plants. This enhanced nutrient use efficiency can lead to increased crop yields while minimizing the environmental impact.

2.3 Reduced Environmental Impact

The controlled release and increased efficiency of Nano fertilizers can significantly reduce the risk of nutrient runoff into water bodies and groundwater contamination. This has the potential to mitigate water pollution and decrease the environmental footprint associated with conventional fertilization practices.

2.4 Customized Nutrient Delivery

Nanotechnology allows for the precise engineering of nanoparticles to release nutrients gradually over time. This enables farmers to customize fertilization strategies based on specific crop requirements, growth stages, and local soil conditions.

2.5 Pest and Disease Management

Nano fertilizers can be combined with pest control agents or antimicrobial nanoparticles to provide integrated pest management. This dual-purpose approach enhances crop protection while simultaneously delivering nutrients.

2.6 Challenges and Considerations

While nano fertilizers hold great promise for sustainable agriculture, there are several challenges and considerations to address:

a. **Safety and Environmental concerns:** The potential ecological and health impacts of nanoparticles in the environment and food chain need careful assessment.

b. **Regulation:** Regulatory frameworks for nano fertilizers vary by region, and there is a need for standardized guidelines to ensure safe and responsible use.

c. **Cost:** The production of nano fertilizers can be more expensive than conventional fertilizer [13], which may limit their adoption by small-scale farmers.

2.7 Future Outlook

Nano fertilizers represent an exciting avenue for improving agricultural sustainability, increasing food production, and reducing environmental degradation. As research and development continue, addressing safety concerns, regulatory frameworks, and cost considerations will be crucial to realizing the full potential of nano fertilizers in modern agriculture

3. NANO-SCALE FERTILIZER INPUT

Nano-scale fertilizers are a relatively new area of research and development in agriculture. These fertilizers are designed to deliver nutrients to plants at the nano-scale level, which can potentially improve nutrient uptake efficiency and reduce environmental impacts. Here are some key points to consider regarding nano-scale fertilizer inputs [14,15]

3.1 Nutrient Delivery

Nano-scale fertilizers are engineered to release nutrients slowly and in a controlled manner, which can enhance nutrient availability to plants. This controlled release can reduce nutrient losses through leaching and runoff [16].

3.2 Nutrient Encapsulation

Nano-fertilizers often encapsulate nutrients within nano-scale materials, such as nanoparticles or nano-coatings. This encapsulation can protect the nutrients from environmental factors and chemical reactions until they are needed by the plant [17].

3.3 Precision Agriculture

Nano-scale fertilizers can be applied with precision, targeting specific plant roots or areas with nutrient deficiencies. This reduces overuse of fertilizers and minimizes nutrient wastage.

3.4 Reduced Environmental Impact

Because nano-fertilizers can enhance nutrient uptake efficiency, they can potentially reduce the environmental impact of conventional fertilizers, which often lead to nutrient runoff and water pollution.

3.5 Challenges

There are challenges associated with the use of nano-scale fertilizers, including concerns about their long-term environmental effects, potential toxicity to plants, and the cost of production. Research is ongoing to address these issues.

3.6 Regulation

The regulatory framework for nano-scale fertilizers varies by country and region (USA, Canada, Australia, New Zealand, Russia, Japan, Korea, Japan, Iran, Thailand, South Africa, India, Brazil). As with any new technology, it's important to adhere to local regulations and safety guidelines when using these products.

3.7 Research and Development

The field of nano-scale fertilizers is still evolving, and ongoing research is necessary to fully understand their benefits and potential drawbacks. Farmers and researchers should stay informed about the latest developments in this area.

4. NITROGEN-BASED NANOPARTICLES AS A FERTILIZER

Nitrogen-based nanoparticles as a fertilizer are a specific type of nano-fertilizer that focuses on delivering nitrogen nutrients to plants more efficiently. Nitrogen is a crucial nutrient for plant growth, and traditional nitrogen fertilizers can be associated with issues like leaching, volatilization, and environmental pollution [18-20].

5. PHOSPHORUS NANO-FERTILIZERS

Phosphorus nano-fertilizers, also known as nano-phosphorus fertilizers, are a specialized type of nano-fertilizer designed to improve the efficiency of phosphorus nutrient delivery to plants [21, 22]. Phosphorus is an essential nutrient for plant growth, and traditional phosphorus fertilizers can be associated with issues like low nutrient use efficiency, phosphorus runoff, and environmental pollution [23-25].

6. NANO SILICA AS A FERTILIZER FOR PLANT

"Silicon material is also referring between essential and it is not participating in the survival of most plants, but in the nonessential substances for the plant because cause of different environmental stress conditions, the plants can adapt and get benefits in the presence of silica. Therefore, it is worth to study the way Si nanoparticles behave in the agricultural system" [2].

"The role of silicon dioxide (SiO_2) nano-fertilizer in the cucumber (Cucumissativus L.) plant shows increasing plant height, number of leaves, number of fruits (fruit weight) and also the foliar spray of SiO_2 improve growth parameter of cucumber (*Cucumis sativus*) once compare with untreated [26]. Nano silica particles absorbed by roots will enhance the plant's resistance to stress and improve yields because the absorbed silica forms films around the cell walls of the plant. The researchers have been reported that improves seed germination, increases plant fresh weight, dry weight, and chlorophyll content with proline accumulation in tomato (*Solanum Lycopersicum)* and squash plants under NaCl stress with the application of nano-SiO_2" [27].

"Besides, the foliar application of nano-Si at 2.5mM concentration significantly improves Cd stress tolerance in rice plants by regulating Cd (Cadmium) concentration, as well as it showed that nano-Si is also effective against Pb, Cu, and Zn with Cd. Nano-Si fertilizers may have an advantage over traditional fertilizers in reducing heavy metal accumulation by the plant" [28]. "Nanomaterials like nano-SiO_2 or nano-ZnO application increases the accumulation of free proline and amino acids, nutrients and water uptake, and activity of antioxidant enzymes including superoxide dismutase, catalase, peroxidase, nitrate reductase, and glutathione reductase, which ultimately improve plant tolerance to extreme climate events" [29].

7. TITANIUM OXIDE NANOPARTICLE AS A FERTILIZER

Titanium oxide nanoparticles have been explored for various applications in agriculture, including their potential use as a component of nano-fertilizers [30, 31].

8. ZINC OXIDE NANOPARTICLES AS A FERTILIZER

"Zinc oxide (ZnO) nanoparticles have been studied for their potential use as a fertilizer in agriculture. Zinc is an essential micronutrient for plants, and zinc deficiency can lead to reduced crop yields and quality. Other than the above applications, the ZnO nanoparticles provide change to improve the growth of rice (Oryza sativa). The application of Zinc oxide nanoparticles significantly improved the growth, yield, and yield-attributing characters in rice cv. PR-121 grown in Zn-deficient soil. The microbial counts and the dehydrogenase enzyme activity were also improved by foliar application of Zinc oxide nanoparticles. This study confirmed the potential of foliar application of zinc micronutrient nano-fertilizer for remediation of the Zn-deficiency symptoms in rice cv. PR-121. Further, it also showed enhanced growth, yield, and grain Zn contents of rice plant besides improvement of the chemical and microbial characteristics of Zn-deficient soil" [32-38].

9. COPPER OXIDE NANOPARTICLES AS A FERTILIZER

Copper oxide (CuO) nanoparticles have been studied for their potential applications in agriculture, including their use as a fertilizer or soil amendment. However, it's important to note that the use of nanoparticles in agriculture is a topic of ongoing research and has both potential benefits and concerns [38, 39]. The CuO nanoparticles have the ability to penetrate plant cells and translocate inside roots and shoots has also been used for the delivery of biomolecules such as DNA and protein, the penetration of CuO NPs in the cell wall [41], corroborating the potential of nano-sized species to serve as a nutrient carrier in plants.

10. CARBON NANOTUBES AS A FERTILIZER

The use of carbon nanotubes (CNTs) as a fertilizer is an emerging area of research and innovation in agriculture. Carbon nanotubes are nano-scale carbon structures with unique properties, and they have the potential to offer several benefits in agriculture (improvement in seed germination, seedling growth, shoot-root length enhancement, enhancement of chlorophyll content and photosynthesis rate, and plant biomass increment in various cereals and horticultural crops). However, it's important to note that this field of study is still in its early stages, and there are both opportunities and challenges associated with using CNTs as a fertilizer [42, 43].

11. CONCLUSION

In conclusion, nanotechnology has the potential to revolutionize the field of organic fertilizers by offering innovative solutions to address various agricultural challenges. While the application of nanotechnology in organic fertilizers is still an evolving area of research and development. Nanotechnology holds promise for enhancing the effectiveness and sustainability of organic fertilizers, contributing to more efficient and environmentally responsible agriculture. However, the responsible development and application of nanotechnology in organic fertilizers require a multidisciplinary approach that considers agronomic, environmental, and safety aspects. As research and innovation in this field continue to advance, it will be important to strike a balance between harnessing the benefits of nanotechnology and addressing potential risks to ensure its successful integration into organic farming practices.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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