Nano Fertilizer Synthesis and Use for Quality Crop Production

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ABSTRACT

Global population is rapidly increasing and is predicted to reach 9.7 billion by 2050. The limited resources tend to push the sector forward, demanding the development of highly efficient agriculture, thus allowing the reduction of worldwide poverty and hunger (Zulfiqar et al. 2019). Hence, chemical fertilizers have been considered an inevitable source of plant nutrition for improving crop production. This led to farmers' notion that using higher doses of chemical fertilizers gains higher crop yields. In addition, farmers frequently apply fertilizers to get targeted production levels. This overuse of chemical fertilizers counteracts the beneficial effects and raises salt concentration in the soil, which might result in crop losses in the future. Furthermore, irregular use of fertilizers without control of nutrient release patterns causes product quality deterioration. Therefore, developing slow or controlled-release fertilizers plays a crucial role not only in enhancing crop production, productivity, and quality but also in upgrading sustainability in agricultural production. Due to the advance properties of nanomaterials, such as high surface-to-volume ratio, controlled-release of nutrients to the targeted sites and absorption capacity, nanotechnology is highly important when designing and using these new fertilizers. Nano fertilizers are nutrients encapsulated or coated with different types of nanomaterials for the

slow delivery and control of one or more nutrients in order to satisfy the plants nutrient requirements (Solanki et al. 2016). These "smart fertilizers" are now being referred to as a potential substitute, to the extent that they are the preferred form of fertilizers over the conventional ones in several cases.

INTRODUCTION

The current world population of 8.05 billion is predicted to 9.7 billion by 2050, according to the FAO report. If all these people are to be fed sufficiently, total food consumption will have to be increased by 50-70%. The limited resources tend to push the agriculture sector forward, demanding the development of highly efficient agriculture to ensure food security (Meghana et al. 2021). Moreover, synthetic fertilizers greatly impact the world's food security and without them, only half of the food production we produce now would be lost (Stewart and Roberts 2012). However, only less than half of the amount of applied fertilizers is utilized by the crop, whereas the remaining amount of fertilizer, which is intended to be taken up by plants, may get lost through leaching, become fixed in soil or contribute to water and soil pollution, which is even worse. According to statistical reports, it has been observed that the key macronutrient elements nitrogen, phosphorous and potassium applied to the soil are lost at a rate of 40-70, 80-90 and 50-90%, respectively, thus causing a considerable loss of applied resources (Rakshit et al. 2012). Using nano fertilizers is one of the strategies that can help enhance fertilizer use efficiency and reduce the harmful impact of chemical fertilizers on the environment. Considering resource use efficiency and safety, nanotechnology can precisely detect and deliver accurate quantities of nutrients to crops, thereby reducing the residual effect on soil (Subramanian and Tarafdar 2011).

Nano fertilizers versus conventional fertilizers

Table 1: Difference between nano fertilizers and conventional fertilizers (Thavaseelan and Priyadarshana (2021)

Properties	Nano fertilizer	Conventional fertilizer
Rate of nutrient loss	Low loss of fertilizer nutrients	High loss rate through drifting, leaching, run-off, etc.
Controlled release	The rate of release and release pattern are precisely controlled	The rate of release and release pattern are not controlled
Solubility	High	Low
Bioavailability	High	Low
Dispersion of mineral micronutrients	Improved dispersion of insoluble nutrients	Lower solubility due to large-size particle
Effective duration of release	Effective and extended duration	Uses at the plant site while the rest is converted into an insoluble form
The efficiency of nutrient uptake	Enhanced uptake ratio and saves fertilizer resource	Low efficiency of nutrient uptake
Soil adsorption and fixation	Reduced	High

Synthesis of nano fertilizer

Nanomaterials for nanofertilizers can be synthesized by different approaches like top-down and bottom-up, under which different physical, chemical and biological methods are used. The top-down approach is based on the reduction of size to nanoscale well-organized assemblies from the bulk materials. The limitation of this approach is the low control of the size of nanoparticles and a greater quantity of impurities (Subramanian and Tarafdar 2011). The bottom-up approach initiates at a very basic level, using atomic or molecular-level chemical reactions to build up nanoparticles. Being a chemically controlled process, this approach has the benefit of controlling the particle size and reducing the impurities in a better way (Zulfiqar et al. 2019).

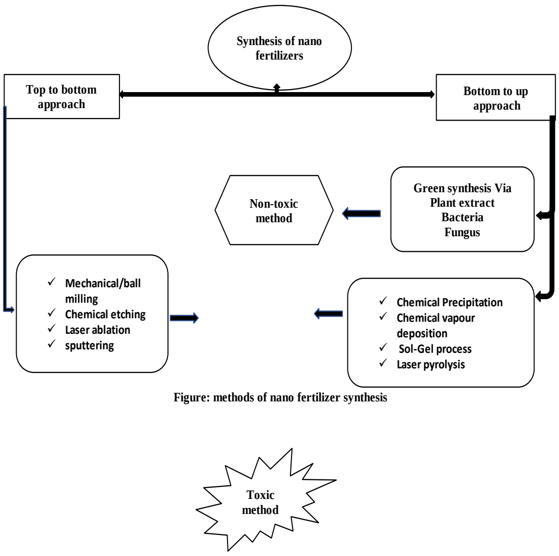


Figure: methods of nano fertilizer synthesis

Types of nanomaterials

• Carbon-based nanomaterials

• Metal-based nanomaterials

• Dendrimers

• Nanocomposites

Unique properties of nano fertilizers

- Smaller size, larger surface area
- Increased surface area to volume ratio
- Slow release
- Specific release
- Pass through the plant and animal cell

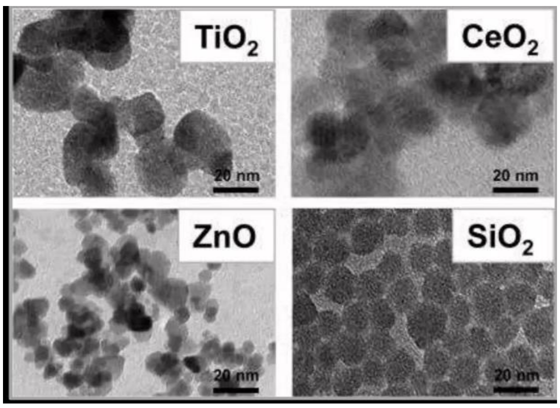
Characterization of Nano fertilizers

Transmission Electron Microscopy (TEM): Transmits a beam of electrons through an ultra-thin specimen, which interacts with the beam. An image is formed of the particle with the help of electrons, which is then magnified and focused on a fluorescent screen, which is then detected. It provides the 3-dimensional measurements of the nanoparticles along with their composition.

Scanning Electron Microscopy (SEM): It uses raster scan pattern with a high-energy beam of electrons to image the sample's surface. This produces signals that reconstruct the sample using information provided, such as topography, composition, conductivity, etc. The SEM produces a variety of signals like secondary electrons, X-rays, light and many more. The first SEM image was produced by Max Knoll in 1935. The SEM gives information on the surface structure of the particle. While using SEM, the sample must be solid and must fit in the experiment chamber.

Dynamic Light Scattering (DLS): Estimate particle size by measuring the rate of fluctuations in the laser light intensity scattered by particles as they diffuse through the solvent.

Particle Size Analyzer (PSA): This technique is used to determine the particle size distribution along with the behaviour of complex fluids. In this method, the light hits



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the nanoparticles and is scattered in all directions. Larger particles scatter more light than smaller particles. The reason for this is that there is more area of contact for the larger particle.

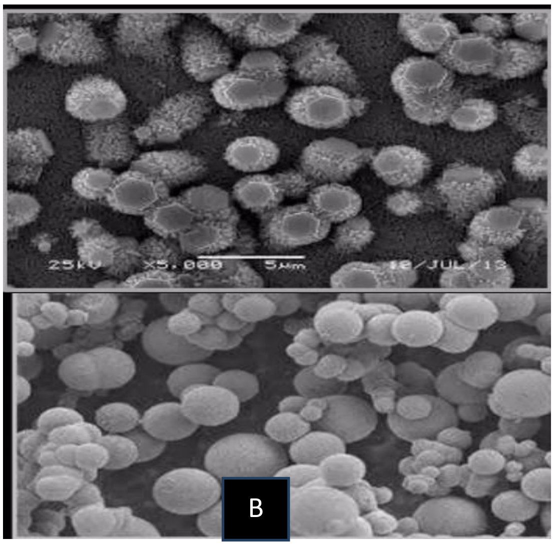

Figure: (A) TEM image of nanoparticles **(B)** SEM image of nanoparticles

Use for quality crop production

Nanoparticles interact with plants in a variety of ways depending on their chemical makeup, size, surface area and sensitivity. These interactions result in severe morphological, anatomical and physiological changes and are crucial for high-quality crop production. Using nano fertilizers improves growth, biomass production, chlorophyll content, sugar level, accumulation of osmolytes and antioxidant production along with the enhancement in expression of stress-related genes, which elevate protein and chlorophyll content and promote nitrogen metabolism under abiotic stress conditions. Additionally, enhancement in nutrient availability, uptake by plants, soil microbial population, soil fertility and growth inhibition of plant pathogens are some of the other beneficial effects of using nano fertilizers (Al-Khayri et al. 2023).

CONCLUSION

The synthesis of nanofertilizers involves physical, chemical and biological methods. Physical methods offer simplicity and scalability, whereas chemical methods allow precise control over morphology and particle size. Biological methods provide environmentally friendly alternatives using plant extracts and microorganisms. The use of various nano fertilizers has an exceptional impact on crop production by enhancing soil health, crop growth, yield, quality, biotic or abiotic tolerance and nutrient use efficiency.

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