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Nanofertilizers: Applications and Future Prospects

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Introduction

The global population is growing at an alarming rate, which has increased the demand for food continuously and is predictable to rise by 70% up to 2050. As the global population is increasing, the demand for food is also increasing day by day, which has compelled the growers toward large-scale use of fertilizers. For solving these problems in crop production nano-fertilizers, pesticides and herbicides may be effectivetools in agriculture for better pest and nutrient management. The word "Nano" means one-billionth, so nanotechnology refers to materials that are measured in a billionth of a meter (nm). The field of nanotechnology has resulted in several advances in chemistry, physics, pharmaceuticals, engineering, and biology. The size of a nanomaterial is typically about 1 to 100 manometers. They can be naturally occurring or engineered.

Nanofertilizers

Nano fertilizers are synthesized or modified form of traditional fertilizers, fertilizers bulk materials or extracted from different vegetative or reproductive parts of the plant by different chemical, physical, mechanical, or biological methods with the use of Nano technological tools used to improve soil fertility, productivity and quality of agricultural produces. Nanofertilizers improve the bioavailability of nutrients owing to high specific surface area, mini size, and more reactivity. The encapsulation of nutrients with nanomaterials can be done in three different ways:

1. Entrapped/encapsulated within the nanomaterials.

2. Coated with a layer of nanomaterials.

3. Delivered in the form of nanoemulsions.

Nanofertilizers have been classified into three groups:

1. Nanoformulation of micronutrients.

2. Nanoformulation of macronutrients.

3. Nutrients-loaded nanomaterials.

Macronutrient-Based Nanofertilizers

Nitrogen Nanofertilizers: Nitrogen is the first and foremost nutrient essential for plant growth as it is important for energy metabolism and protein synthesis. N nanofertilizer formulations and found a consistent increase in growth, yield, quality, and nutrient uptake in crop with respect to conventional urea. Nitrogen nanofertilizer which is based Zeolite not only indicated higher accumulation of N in plants but also the post-effect of application in soil exhibited better pH, moisture, and available nitrogen than the conventional fertilizer.

Phosphorous Nanofertilizers: P is essential for transporting and storing energy, photosynthesis execution, and organic compound formation. In conventional fertilizers complexes with iron, aluminium hydroxides, and calcium in the soil or its immobilization with clay particles in the soil restricts its availability. Only 10–20% of the supplied P fertilizers are taken up by plants. So, to overcome these problems, several researchers have formulated and evaluated nanotechnology-based approach for phosphorus fertilizers. Such as nanohydroxyapatite-based fertilizer with respect to regular P fertilizers. The use of hydroxyapatite NPs led to enhanced plant growth parameters, chemical contents, and anticancer activity of leaves in comparison to different sources of P Nanofertilizers.

Potassium Nanofertilizers: The role of potassium includes regulation of water, transport of the plant's reserve substances, enhancement of photosynthesis capacity, strengthening of cell tissue, stimulation of flowering, and synthesis of carbohydrates and enzymes. Nano-K was most effective in increasing the leaf area, grain yield, biological yield, harvest index, potassium percentage, and chlorophyll content, disease and pest resistance, and drought tolerance owing to improved nutrient absorption.

Calcium Nanofertilizers: Calcium plays a significant role in various processes such as cell wall stabilization, mineral retention in soil and their transportation, neutralizing toxic substances, and seed formation. Spraying of nanofertilizer at a concentration of 500 mg/L resulted in flowering about 15 days prior to control plants along with 56.3% increase in the number of flowers. Ca-nanofertilizer significantly reduced fruit cracking and increased the yield.

Magnesium Nanofertilizers: Magnesium is a vital element for plant growth as it main composition in the core of the chlorophyll molecule, thus becoming crucial for photosynthesis. It also acts as an enzyme activator. Magnesium hydroxide nanofertilizer have also been explored for their efficacy in seed germination as well as in vitro and in vivo plant growth promotion.

Sulphur Nanofertilizers: Sulphur contributes to chlorophyll formation and increases nitrogen efficiency as well as plant defences. It was observed that sulphur Nanofertilizers decreased Mn uptake, enhanced S metabolism, elevated the water content of seedlings, and eliminated physiological drought, indicating that sulphur Nanofertilizers can limit the deleterious effects of Mn stress.

Micronutrient-Based Nanofertilizers:

Iron Nanofertilizers: Iron acts as an important cofactor for enzymes dealing with numerous biological processes in plants. A promising approach to make iron available to plants is the use of highly stable and slow release nanoformulations. Iron chelate nanofertilizer is highly stable and provides slow release of iron in a broad pH range. Iron nanofertilizer significant increase in growth parameters, photosynthetic pigments, and total protein contents.

Zinc Nanofertilizers: Zinc is important for the catalytic activity of various metabolic enzymes, cell division, tryptophan synthesis, photosynthesis, protein synthesis, and in the maintenance of membrane structure and potential. Application of zinc nanofertilizers to plants can be accomplished by various methods such as by soil mixing, foliar spray, and/or seed-priming method. Out of these, the seed-priming method is simple, more efficient, and cost effective. Foliar application of zinc oxide nanofertilizers resulted in enhanced petal anthocyanin and leaf chlorophyll content along with increased number of leaf, lateral branches, and flowers.

Copper Nanofertilizers: Copper is a crucial micronutrient for several important physiological functions, including mitochondrial respiration, cellular transportation, antioxidative activity, protein trafficking and hormone signalling of plants. Improvement in stress tolerance in wheat was achieved with the employment of Cu nanofertilizers. A substantial increase in root length, height, fresh and dry weights of pigeon pea seedlings was noticed when treated with biogenic Cu nanofertilizers having 20 nm size.

Molybdenum Nanofertilizers: Molybdenum is required in very small quantities. The range is between 0.3 and 1.5 ppm for most of plant tissue and between 0.01 and 0.20 ppm for a growing medium. Mo nanofertilizers solution as a micronutrient source of Mo for chickpea and reported that application of Mo nanofertilizers intact or in combination with microbial treatment had the potential to improve the yield, performance, and disease resistance of legume as well as other crop species.

Biofertilizers-Based Nanofertilizers: A biofertilizer is exclusively composed of biologically useful microorganisms such as rhizobium, blue-green algae, mycorrhizae, bacterium azotobacter, azospirillum, phosphate-dissolving bacteria such as Pseudomonas and Bacillus species. The nanoscale formulation of a biofertilizer conferring structural protection to biofertilizer nutrients and plant-growth-promoting bacteria, via nanoencapsulation-mediated coating of nanoscale polymers. The nanoencapsulation approach could be used as a dynamic mechanism to elongate the structural protection of being delivered biofertilizer, enhance its chemical shelf life and dispersion in fertilizer formulation, allowing a controlled release.

Advantages of Nanofertilizers:

1. Enhanced nutritional security in plant system.
2. Improve uptake and nutrient use efficacy of crop plants.
3. Prevent the loss of nutrients.
4. Improved pests and pathogen resistance.
5. Reduce the demand for fertilizers.
6. Improve water-holding capacity and soil quality.

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7. Increase microbial activity.

Disadvantages of Nanofertilizers:

1. High cost of nanofertilizers.
2. Nanomaterials can interact with soil components and may cause toxicity.
3. Nanofertilizers can accumulate in plant parts, leading to growth inhibition, generation of reactive oxygen species, and cell death.
4. Can accumulate in food parts and, when consumed, may cause human health problems.
5. Reactivity and variability of nanomaterials have raised safety concerns for workers.

Prospects: Developing countries such as India and several others have extensive agriculture practices, which are being mitigated in the rural background. Getting the backing of farmers (who are the real stakeholders) in such intriguing circumstances. So, there is a need to make grassroot efforts in awakening the farming community and farmers about the positives of nanocarrier-mediated fertilizer delivery. Nanofertilizers could play in enhancing the efficiency of transport, delivery, and plant uptake of nutrients which would enable their optimal use. Therefore, scientists and media personnel must initiate harmonious and committed joint efforts along with reliable governmental support so that the exact scientific rationale for nanofertilizer usage is understood.

Conclusion: The scientific essence of nanofertilizers is to boost agricultural outputs, characterized by correct selection and uniform dispersal of seeds, thorough irrigation and adequate as well as regulated use of fertilizers. Several factors determine this phenomenon, including soil type, chemical combination with other nutrients, leaching effect, and uptake efficiency of plants. Nanobiofertilizers hold a great potential to boost the agricultural output at the desired rate when used in optimum concentrations while overcoming the limitations of conventional fertilizers.