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# Nano-Pesticides and Nano-Fertilizers for Sustainable Agriculture

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The world's agricultural sector has advanced remarkably in the previous several decades. Thanks to technological innovations and improved agricultural practices, we have produced more food to fulfill our population's demands. However, by the end of the century, there will be nine billion people on the planet, posing a significant challenge to food supply and it also means global food demand will increase further over the next 40 years. Recent studies suggest that by 2050, world food demand will increase by 70 to 100 percent. At the same time, droughts, floods, and severe temperatures caused by climate change all pose a threat to agricultural development and production, further exacerbating food security concerns (Bhattacharya, 2019). Improving food supply and quality has become a primary issue due to the world's population growth, climate change, and growing natural resource scarcity. At the same time, it is critical to address how the environment affects the food chain.

This includes overfishing, which affects our ability to produce food, and increased competition for energy and land. In recent years, a lot of attention has been paid to figuring out sustainable solutions to meet the world's food needs. The term "nanotechnology" is frequently used to characterize structures made of tiny pieces that are assembled in bottom-up or top-down ways to form structures as large as hundreds of nanometers. The term 'Nano' is derived from the Greek word it's meaning dwarf $10^{-9}$ almost 1 to 100nm. The term nanotechnology is given by Norio Taniguchi. Nanotechnology is a newly emerging technology in which the structure of the matter is controlled at the nanoscale to produce a material having unique properties or nanotechnology is the art and science of manipulating matter at the nanoscale. The National Nanotechnology Initiative's most stringent definition of nanotechnology applies to structures having at least one dimension between one and one hundred nanometers. Nowadays, nanotechnology is used in many industries, including agriculture, environmental protection, food processing and packaging, textile, and construction, among others, posing fresh possibilities and difficulties for established industrial technology. The application of nano pesticides and fertilizers in agriculture is where nanotechnology is most visible. Because of their unique properties, which include a large surface and controlled release, nanomaterials are perfect for increasing agricultural output (Yetisen *et al.*, 2016). Nano-pesticides are the best alternative to increase solubility, dispersion, bioavailability, to protect against premature degradation and for the targeted release of active ingredients are Controlled release based on light, pH, humidity, and the temperature is possible through nano pesticides. In nature, essential oils with an insecticidal property are extremely volatile, sensitive to UV rays, and degrade when exposed to sunlight. Loading of these essential oils into nanoparticles will mitigate such problems and convert these essential oils as good pesticidal candidates.

## Nano-Fertilizers in Farming

Nano-fertilizers, emerging from advancements in nanotechnology, exhibit diverse properties catering to specific nutrient requirements. They are mainly divided into macro nutrient element nano-fertilizers and micro-nutrient element nano-fertilizers in terms of nutrient elements. For macro-nutrient elements, such as nitrogen, phosphorus, and potassium, processing them into nanoscale may change their bio-effectiveness as well as the way of crop absorption (Chhipa, 2017). Taking the macronutrient element nitrogen as an example, nano-nitrogen fertilizer can improve the diffusion speed of nitrogen in the soil, improve its effectiveness, and improve the efficiency of plant nitrogen absorption. Overall, nano-fertilizers are supplied through root or foliar application, then transferred to the above-ground part via the root endodermis and epidermis, or taken up by leaf pores and carried via the phloem. Nanoparticles can penetrate plant cells directly via the cell wall structure and reach the plasma membrane when they are smaller than the cell membrane particle sizes (5–20 nm). When nanoparticles attach to various cytoplasmic organelles, metabolic activities can be interfered with. Engagement with designed nanoparticles has the potential to enlarge pores or induce new cell wall pores, hence increasing nanoparticle absorption.

## Application of Nano-Nitrogen Fertilizer

Fertilizers have played a pivotal role in enhancing the food grain production in India especially after the introduction of high yielding and fertilizer responsive crop varieties during the green revolution era. The utilization of nano-nitrogen fertilizers exhibits noteworthy advantages in aug menting nitrogen use efficiency. Owing to their diminutive particle size, nano-nitrogen fertilizers exhibit enhanced binding to soil particles, prolonging the retention time of ni trogen in the soil. This attribute serves to mitigate volatilization and leaching losses of The utilization of nano-nitrogen fertilizers exhibits noteworthy advantages in augmenting nitrogen use efficiency (Upadhyay *et al*., 2023). Owing to their diminutive particle size, nano-nitro gen fertilizers exhibit enhanced binding to soil particles, prolonging the retention time of nitrogen in the soil. This attribute serves to mitigate volatilization and leaching losses of nitrogen. The precise and targeted release mechanism associated with nano-nitrogen fertilizers contributes to more efficient uptake of nitrogen by plants during critical growth stages, thereby minimizing nitrogen waste. Moreover, the size effect of nano-nitrogen fertilizers assumes a pivotal role in inter root interactions. The reduced size facilitates easier penetration of the plant root system, enhancing the efficiency of nitrogen uptake. The precision of the release mechanism in nano-nitrogen fertilizers results in a more consistent and even supply of nitrogen, contributing to the maintenance of stable nitrogen levels in crops throughout the growth cycle. This is anticipated to mitigate the issue of nitrogen oversupply associated with conventional nitrogen fertilizer, thereby addressing environmental concerns. Nanomaterials have potential contributions in slow release of fertilizers. Nanocoatings or surface coatings of nanomaterials, on fertilizer particles hold the material more strongly from the plant due to higher surface tension than conventional surfaces. Moreover, nanocoatings provide surface protection for larger particles. Fertilizers with a sulfur nanocoating (a layer of less than 100 nm) are beneficial slow-release fertilizers because of their beneficial sulfur content, particularly for soils that are sulfur deficient. The coating's durability slowed the fertilizer's rate of disintegration and permitted a gradual, prolonged release of sulfur-coated fertilizer. To address the needs of the soil and crops, sulfur nanocoatings or the encapsulation and release of urea and phosphate will be beneficial.

## Nano-Pesticides in Agriculture

The application of nanotechnology to the pesticide industry offers novel approaches to traditional farming methods. Nanopesticide formulations or products that contain engineered nanoparticles with biocidal properties are known as nano-pesticides, and they can take many different forms, including lipids, polymers, and metal organic frameworks. These materials have varying mechanisms for pesticide delivery and release, and polymer-based nano-pesticides may be able to precisely control pesticide attachment and release on crop surfaces due to the tenability of their microstructures. The distinctive properties of nanoparticles in pesticides offer unique advantages for plant protection applications. The significant increase in surface area makes it easier for nano-pesticides to engage with plant surfaces, which improves adhesion effects. Additionally, the enhanced penetration capacity of nanoparticles allows for deeper penetration into plant tissues, leading to more thorough control effects, in addition to speeding up pesticide delivery. There are many different and intricate ways that nanopesticides work on pests. Nanopesticides may increase adsorption and adhesion to pests by creating microscopic traps on crop surfaces through their mesoporous qualities. A change in solubility could cause the pesticide to be released more gradually, making it more hazardous to the bug. The way active substances are released, such the surface reactivity of nanocarriers, may enable insecticides to target pest physiological systems more precisely, enhancing their deadly effects. Smaller nanoparticles have better penetration capacities via plant roots and epidermis, allowing pesticides to be distributed more widely within the plant and increasing their effectiveness against pests (Abd El-Azeim *et al*., 2020). NPs can significantly improve the durability and effectiveness of entire cells, enzymes, and other natural products used in biopesticides. However, there are a number of obstacles to using NPs in the field to deliver pesticides and biopesticides, including numerous environmental disturbances, wide areas covered by spray, and ultimately, cost effectiveness. For convenience of application, the chemical is sprayed on the entire crop in the standard spraying regime, which involves a high volume, low value preparation. On the other hand, limited volume, high value applications are anticipated for preparations based on nanomaterials. Such regulated nanoparticulate delivery devices will necessitate a tailored distribution strategy based on an understanding of the pathogen or pest's life cycle and behavior.

**Table 1: Comparison of nanotechnologybased formulations and conventional fertilizers applications (Cui *et al*., 2010)**

| Properties | Nano-fertilizers-enabled technologies | Conventional technology |
|---|---|---|
| **Solubility and dispersion of mineral micronutrients** | Nano-sized formulation of mineral micronutrients may improve solubility and dispersion of insoluble nutrients in soil, reduce soil absorptionand fixation, and increase the bioavailability | Less bioavailability to plants due to large particle size and less solubility |
| **Nutrient uptake efficiency** | Nano structured formulation might increase fertilizer efficiency and uptake ratio of the soil nutrients in crop production and save fertilizer | Bulk composite is not available for roots resource and decrease efficiency |
| **Effective duration of nutrient release** | Nanostructured formulation can extend effective duration of nutrient supply of fertilizers into soil | Used by the plants at the time of delivery, the rest is converted into insoluble salts in the soil |
| **Loss rate of fertilizer nutrients** | Nanostructured formulation can reduce loss rate of fertilizer nutrients into soil by leaching and/or leaking | High loss rate by leaching, rain off, and drift |

## Conclusion

The widespread use of agrochemicals to increase agricultural output in the modern agricultural environment has contaminated not just the top soil, groundwater, and food. While raising agricultural productivity is vital, new strategies must be taken into account in light of the harm to the ecosystem. The use of nanotechnology in agriculture is growing in significance. In the fields of fertilizer delivery, pesticide delivery, biopesticide delivery, and genetic material for plant transformation, promising outcomes and applications are already being created. It is anticipated that using nanoparticles to administer fertilizers and pesticides will result in a lower dosage and more regulated, gradual distribution. By taking advantage of the special qualities of nanomaterials, nanotechnology has created nano-sensors that can identify infections at concentrations as low as parts per billion.

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