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# Path towards Sustainable Agriculture with Agro-Nanotechnology

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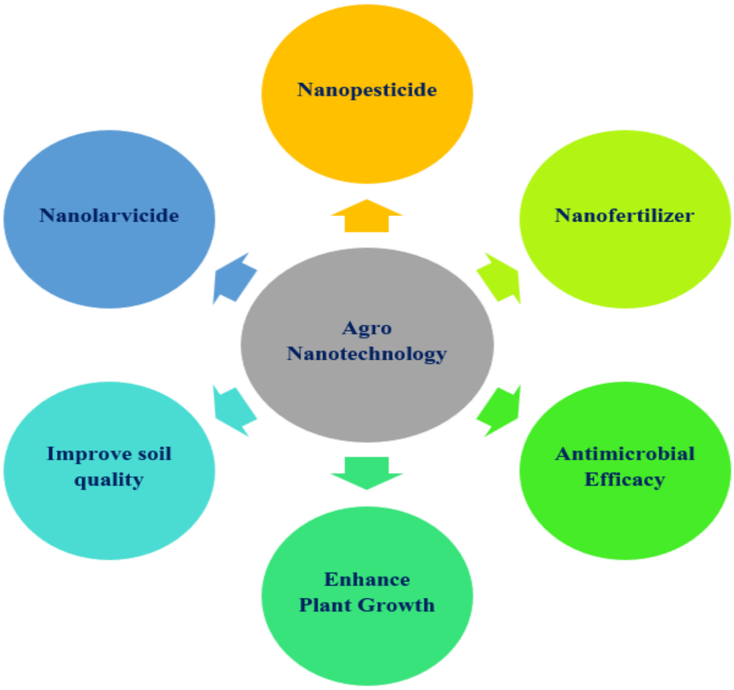
**ARTICLE ID: 51**

## Introduction

All throughout the world, agriculture is integrating more and more nanotechnology. Traditional agricultural methods resulted in the usage of chemical fertilizers, which caused a number of issues such soil pollution, soil salinity, soil acidity, water contamination, and insect resistance in some crops. These methods have reached their capacity and can no longer be used to increase productivity or repair ecosystems damaged by current technologies. Using nanostructures with a diameter of 1–100 nm, which may be divided into novel materials, applications, and devices. These nano materials can be synthesized by using top down and bottom-up techniques, respectively. The worldwide requirement for food is continually expanding. By improving the efficiency of nutrient uptake with nano-fertilizers, controlling pests and diseases with nano-pesticides, and other ways, nanotechnology would help modern agriculture. For usage in agricultural areas, nano-sensors are being developed to track the agro-climatic conditions required to increase crop yield and ensure proper management of fertilisers, insecticides, and herbicides. Agro-nanotechnology would be a cost-efficient, eco-friendly, and green technology for sustainable farming as a consequence.

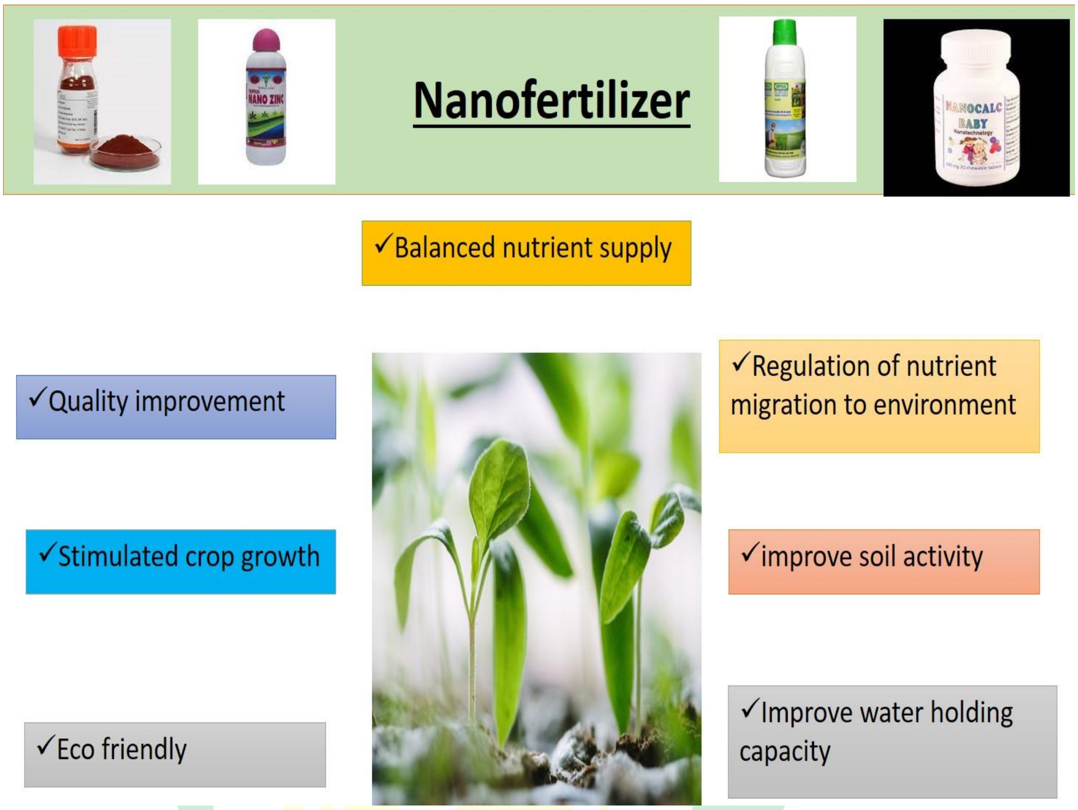
Agro-nanotechnology, which combines agriculture with nanotechnology, focuses on sustainable plant development and improving soil nutrients to increase the production of food crops. It may be used in many phases of agriculture, such as sprouting, processing, managing plant diseases, and many more, from planting seeds to growing harvests. It could be a good idea to construct a high-level agricultural system and employ nano particles in order to revolutionise agricultural methods and lessen the environmental impact of modern agriculture while also improving produce quality and quantity.




## Nanoscience in Agriculture

### 1. Nanofertilizer

The global consumption of fertilisers climbed from 15 to 194 million tonnes in between 1950 and 2020 that become 13-fold increase. Agricultural prices are increasing dramatically every day as a result of the market's limited supply of chemical fertilisers, which negatively affect the environment by releasing chemical particles and causing run-off agriculture. As they are manufactured industrially from a chosen range of microorganisms that either create a mutually beneficial connection with plants or are a part of their rhizosphere, biofertilizers have therefore become a safer supplement to improve crop yield without harming the environment. They nevertheless have significant shortcomings, which prompted the creation of a brand-new field in which to use nanotechnology-based fertilisers.Significant opportunities for customizing the manufacturing of nanofertilizers are suggested by nanotechnology. They are normally coated with the required chemical composition, which has the capacity to increase plant production and reduce environmental pollutants. It also has controlled release and targeted delivery of beneficial nanoscale components. The usefulness of nanofertilizers, would also provide helpful information about the introduction of various types of nanofertilizers into the agriculture sector, offering up a new path to the nanorevolution.




2. **Nano pesticide**

Environmental problems associated with the careless use of chemical pesticides include environmental pollution and the pests and diseases tolerance development. Concerns over the environment, food safety, and soil health have grown significantly. By creating nano-pesticides, nanotechnology offers an unbreakable answer to these issues. The conveyor molecules or functional elements are at nano scale level. These nano particles operate significantly better than conventional insecticides due to their smaller size, which facilitates appropriate distribution on pest surfaces. Some of the most important benefits of nanoparticles include improved solubility, formulation stability, progressive liberation of operational components, and increased mobility. These benefits are due to the nanoparticles' small size and larger surface area. In compared to bulk materials, nanoparticles have stronger action against their target pests. Additionally, by providing systemic qualities, uniform leaf coverage, and improved soil properties, nano-formulations prolong productive usage in agriculture.

3. **Nano-sensor**

The "Nano" scale is where nano sensors operate. Nano sensors can be used to track physical characteristics like temperature on the nano scale or to detect chemical or mechanical information, such as the presence of chemical species and nano particles. On the basis of their composition and intended use, nano sensors can be categorised. Nano sensors may be divided into two categories based on their structural differences: optical nano sensors and electrochemical nano sensors. The nano sensor can be classed as a chemical nano sensor, biosensor, electrometer, or deployable nano sensor depending on the application. The chemical, optical, medicinal, food, and electronics sectors may all use the nano sensor. Particularly exciting uses for nano sensors include chemical detection, food and water quality monitoring, and medical diagnostic applications. One of the most exciting applications for many nano sensors is optical signal detection. Many other classes of nano sensors are feasible depending on their optical selectivity. They include nano sensors based on carbon nano tubes, QDs, photo acoustics, and other technologies.

4. **Soil quality Enhancement**

According to studies, hydrogels, nano clays, and nano zeolites increase soil's ability to store water, functioning as a slow-release source of water and minimising dry spells throughout crop season. Applications of such systems are advantageous for reforestation of degraded regions as well as for agricultural applications. Nanomaterials, both organic (like polymers and carbon nano tubes) and inorganic (like nano metals and metal oxides), have been utilised to absorb environmental toxins, improving soil remediation capacity and decreasing treatment cost and time.

5. **Plant growth Stimulation**

By improving nutrient absorption and use of elements, carbon nano tubes and nano particles of Au, $SiO_2$, ZnO, and $TiO_2$ can help improve plant growth. However, in addition to the vulnerability of the plant species, the true effect of nano materials on depends primarily on their composition, quantity, size, surface charge, and physical and chemical characteristics. The creation of novel procedures and the use of various analytical methods (such as microscopy, magnetic resonance imaging, and

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fluorescence spectroscopy) might significantly advance our understanding of how plants interact with nanostructures.

6. **Plant Disease management**

Nano materials [NPs; size, 1-100 nm] have recently become recognised as distinct antibacterial agents. In particular, several classes of antimicrobial NPs and nanosized carriers for antibiotic delivery have demonstrated their efficacy for treating infectious diseases, including those that are antibiotic-resistant, in vitro and in animal models. These agents can provide better therapy than conventional drugs due to their high surface area-to-volume ratio, which causes the emergence of novel mechanical, chemical, electrical, optical, magnetic, electro-optical, and magneto-optical properties, in contrast to conventional drugs. So, NPs have been proven to be intriguing in the battle against microorganisms. The toxicity mechanisms change depending on the stain. Even the effectiveness of NP to treat bacteria, drug-resistant bacteria, and their defensive systems varies depending on strains in specific cell wall composition, enzymatic composition, and other factors. As a result, we offer a perspective on NPs in the microbial world a method to combat drug resistance by labelling antibiotics in NPs, as well as its potential for advancement in science. The biosynthesis of AgNPs in this work is carried out utilising an aqueous extract of strawberry waste. Due to their significant antibacterial and antifungal activity, the biosynthesized AgNPs demonstrated antinematode, antibacterial, and antifungal responses against *M. incognita, R. solanacearum,* and *F. oxysporum,* respectively. On fungi studied *In vitro,* the biosynthesized AgNPs demonstrated immediate, strong antifungal effects, likely by crack or rupture of membrane integrity. As a result, we may accept that the biosynthesized AgNPs can be applied to a variety of applications, including the recovery of agricultural productivity, food safety, and others, against plant diseases. The biosynthesized face-centered cubic crystalline AgNPs were evaluated against the nematode *Meloidogyne incognita*, the plant pathogenic *bacterium Ralstonia solanacearum*, and the pathogen *Fusarium oxysporum* for their effectiveness and inhibitory effects. These findings demonstrate that all these plant pathogens may be effectively controlled by biosynthesized AgNPs, AuNps, CuNPs etc..

**Toxicological Effect of Nano materials in Agriculture**

Numerous disciplines have benefited significantly from nanotechnology. Its usage may be able to identify and lessen environmental toxins, but as Figure 3 demonstrates, using such nanomaterials without sufficient expertise can have detrimental impacts on both human health and agricultural fields. Additionally, silica, nano-zinc, iron, titanium dioxide, Zn-Cd-Se/ZnS core shell QDs, etc. may be found in nanofertilizers. One of the main issues with decreasing agricultural output in soils with alkaline pH levels is a zinc deficit.

**Conclusion**

In conclusion, the utilization of nanotechnologies in addition to the introduction of nano particles in agriculture, potentially can contribute significantly to address the issue of sustainability, especially in light of the great challenges we will be facing, especially due to the increasing global population and climate change. In reality, the use of nanoscale transporters and compounds can improve the effective use of fertilizers and pesticides, lowering the quantity that must be sprayed while maintaining yield. While nanosensor technology can promote the spread of precision agriculture, for more effective management of resources, including energy. Not only this, nanotechnologies can also have an influence on reducing waste, leading to both more production efficiency and the recycling of waste.