

Nano-biofertilizers

for sustainable agriculture development under changing climatic conditions

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Precise nutrient management of crops, soil fertility and soil health will be a major challenge worldwide in the future because intensive cropping systems rely predominantly on diverse types of agro-chemicals. The use of conventional or synthetic agro-chemicals suffers from lower nutrient use efficiency, negative impact on the environment and soil health, and higher loss of water bodies. Nano-biotechnology is a promising alternative biological strategy having the potential to revolutionize agricultural systems by delivering nutrients to crops in a controlled release manner. Engineering nano-particle based nano-fertilizers offer benefits in crop nutrition management by enhancing abiotic stress tolerance such as salinity, drought as well as high temperature and improve agricultural productivity in a sustainable way. This article focusses on the role of macronutrient, micronutrient-based nano-fertilizer as well as nano-biofertilizer towards the development of smart and sustainable future agriculture.

Keywords: Intensive cropping system, Nano-biotechnology, Nano-fertilizers, Sustainable agriculture

SINCE green revolution, agro-chemicals are deemed indispensable input intensive cropping systems, but these have associated environmental and ecological consequences. Greater loss of essential nutrients from agricultural fields in the form of leaching and gaseous emissions has been the leading cause of environmental pollution and climate changes. Ensuring the agricultural sustainability of crop production necessitates exploring other essential nutrient sources and modifying existing nutrient sources. Nanotechnology, which utilizes nano-material of less than 100 nm size, may offer an unprecedented opportunity to develop concentrated sources of essential plant nutrients having higher nutrient utilization efficiency, absorption rate and minimum losses under changing climatic conditions. Nano-fertilizers are being prepared by encapsulating essential macro as well as micro-nutrients delivered in

the form of nano-sized emulsions, nano-pores in plant leaves facilitating nano-material uptake and their penetration, deep inside leaves leading to higher nutrient utilization efficiency (NUE). Nano-fertilizers have higher transport and delivery of essential nutrients through plasmodesmata, which are nano-sized (50–60 nm) channels between cells. The higher NUE and significantly lesser nutrient losses of nano-fertilizers leads to higher nutrient accumulation and crop production. Recently, the encapsulation of indigenous micro-organisms with nanoparticles has become an interesting application in agriculture to improve plant root health by reducing essential nutrient leaching and volatilization in the rhizosphere. The soil supplemented with micro-nutrients encapsulated in nano-particles opens the slow release path to promote plant growth, crop productivity, soil fertility and soil health.

Innovative nano-fertilizers: Key to agricultural sustainability

Novel and innovative agro-chemicals apart from enhanced NUE often benefit in terms of reduction in environmental pollution under intensive cropping system. Nano-fertilizers based on nanotechnology because of their size advantage and controlled manufacturing process through chemical, physical and biological means have emerged as a viable option to fulfill this gap in conventional and innovative fertilizer market.

Nano-fertilizers are composed of several nano-particles such as metal oxides, carbon based and other nanoporous materials varying upon their composition and combination properties. The response of crop plants by absorbing nutrients from the soil depends on the morphology and synthesizing criteria of several nano-particles. Modern nano-sized formulation of nano-fertilizers improves the solubility, dispersion of insoluble nutrients,

bioavailability and accessibility of definite delivery to reduce nutrient losses. The nano-formulations were synthesized via different engineered approaches and then encapsulated the required nutrients to increase target-specific plant uptake efficiency. First mechanism, related to nano-fertilizers, plant cell walls were worked as the barrier for self-protection with a pore size of 5–20 nm. Only, the external agent with a lower diameter than plant cells can pass the size exclusion limits (SELs) and develop embedded transport carriers of needed nutrients which are usually applied in soil or surface of the leaves. Thus, nano-assisted fertilizers showed excellent transport characteristics through plant tissues/cells with controlled mobility over conventional water-soluble agro-chemical. The working mechanism of nano-particles is flexible on both root entry and foliar entry.

Types of nano-fertilizers

Macronutrient nano-fertilizers

Macronutrient nano-fertilizers are composed of nutrients (K, P, N, Mg and Ca) which are required in large quantity for the plant growth and development. The conventional fertilizers have low efficiency and they enter into the water bodies (surface and groundwater) which are a threat to aquatic as well as to human life. The application of nano-fertilizers not only reduces the nutrient loss, but also has zero adverse effects on environment. Various factors impact the performance of nano-fertilizers in the soil like pH, texture of soil, organic matter, particle size, route of exposure and nano-fertilizers accumulation in crops. Nano-particles could enter into the plant through intercellular spaces using apoplastic pathway. Further, nano-particles enter into epidermal and cortical cells through cell wall to reach endodermis and accumulate uniformly or as aggregate form.

Nanozeolite: Zeolite boost up the crop production by improving the soil condition through increased biological activity, fertility, enhanced water utilization efficiency and minimizing salinity of

soil and ammonia volatilization. Also, zeolite helped in retaining nutrients in the soil for longer period of time which increased the availability of nutrients in the soil. Therefore, plants can utilize the nutrients for longer period of time as modified zeolites are slowly decomposed and disintegrate.

Nano-hydroxyapatite: Nano-hydroxyapatite $[\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2]$ is generally present in the human hard tissues, teeth and bones. The nano-hydroxyapatite is currently used as an alternative to conventional phosphorus fertilizers. Generally, conventional phosphorus fertilizers are water soluble and very mobile in the soil solution so it can cause eutrophication. Therefore, nano-hydroxyapatite based phosphorus fertilizers are excellent alternative to overcome the issue of eutrophication as nano-hydroxyapatite leads to the slow release of phosphorus. Beside phosphorus, nano-hydroxyapatite can also be utilized for the synthesis of other nutrients nano-fertilizers.

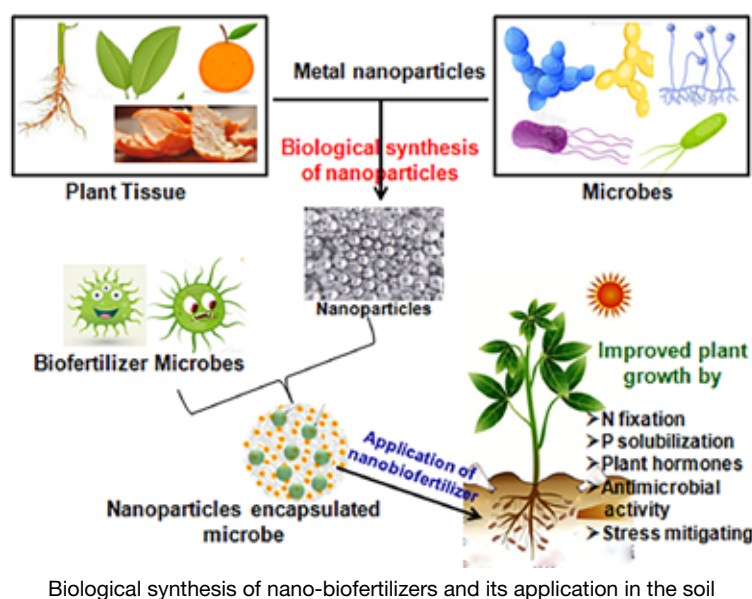
Micronutrients

These are the nutrients (Fe, Mo, Cu, Zn etc) which are required in less quantity but are essential for proper metabolic activities. These micronutrients are sometimes blended with macro-nutrient fertilizers. Iron (Fe) is one of the important micro-nutrients required for the plant growth. Different types of nano-fertilizers of iron (super-paramagnetic Fe nano-particles,

calcium alginate with iron nano-particles, etc) were tested by various researchers in the field condition and results showed remarkable improvement in the plant growth and crop yield. Zinc (Zn) is another important micro-nutrient for plant growth which plays an important role in differentiation and proliferation of cells, chloroplast synthesis and also helps in the activation of many enzymes. Different types of zinc nano-fertilizers are available like as ZnS and ZnSe, or quantum dots CdSe/ZnS but the most important one is zinc oxide nano-particle (ZnONPs).

Nano-biofertilizers: A novel tool for sustainable agriculture

Conventional chemical fertilizers have adverse effect on soil health, long term residual action and toxicity to the environment, whereas biofertilizers are excellent biological tool for sustainable agriculture. Although in intensive agriculture system, fertilizers based on nano-particles play an important role but these nano-particles based fertilizers have their own limitations like impact on the environment, low shelf-life, low stability and performance impact by various factors (radiations, temperature and pH). Under these circumstances nano-particles based biofertilizers, i.e. nano-biofertilizers are wonderful substitute for these nano-particles based fertilizers. Basically these



Biological synthesis of nano-biofertilizers and its application in the soil

Table 1. Impact of nano-biofertilizers application on plant growth promotion in different crops

Plant	Nano-bio fertilizers	Preparation	Response
<i>Triticum secale</i>	Titanium (Ti) (<i>Azorhizobium caulinodans</i>)	Sol-gel method	Maximum grain weight, grain yield, and chlorophyll content were observed. Reduced the harmful effect of reactive oxygen species
<i>Triticum aestivum</i> L.	Zinc (Zn) (<i>Azotobacter</i> and <i>Pseudomonas</i>)	Precipitation method	The nano-biofertilizer increased the spike number and spike length, seed weight, and seed number respectively.
<i>Vigna radiata</i>	Zinc oxide (ZnO) (<i>Pseudomonas fluorescens</i>)	Foliar spray method	ZnO, FeO, and ZnFeCu oxide nano fertilizer showed the increase shoot length of 6.47%, 10.25%, and 15.71%, respectively concerning control. Root biomass was increased around 30.15%, 31.79%, and 58.79% for FeO, ZnO, and ZnFeCu nano-bio fertilizer, respectively.
<i>Vigna raidata</i> L.	NPK (<i>Azotobacter</i>)	Ultra-sonication method	The NPK nano-bio fertilizer improved the enzyme activity and seed vigor index.
<i>Zea maize</i> L.	Chelated (<i>azetobarvar</i> and <i>phosphorbarvar</i>)	Precipitation method	The grain yield of maize production was increased after 7 days of the Zn nano-bio fertilizer application.
<i>Vitis vinifera</i> L.	NPK (<i>Rhizobacteria</i>)	Sol-gel method	A significant role of yield, leaf nutrition, vine growth and quality has been investigated using Ca nano-biofertilizer. It reduced the adverse effect of the abiotic stress on the plant.

nano-biofertilizers are synthesized by modifying nano-particles which are attached to the potential bio-fertilizer microorganisms like *Azotobacter*, *Azospirillum*, *Bacillus*, and *Rhizobium* etc. These attached biofertilizer microorganisms could be able to fix nitrogen, solubilize insoluble phosphorus, degradation of complex matter into simpler one, produce various plant growth hormones etc. By the application of these nano-biofertilizers there is a close interaction between bio-fertilizer microbe, plant and nano-particle. In these interactions, microbes provide nutrients for the plant growth as well as reducing the toxicity of nano-particles (Table 1).

The application of nano-biofertilizers in the soil leads to the increased efficiency of biofertilizer and causes slow and sustained release of nanoparticles in the rhizosphere. The application of nano-biofertilizers not only improved plant growth by the used biofertilizer microbial strain, but also leads to the production of secondary metabolite (enzymatic and non-enzymatic antioxidants) in crop plants. The utilization of nano-biofertilizers also mitigates the effect of toxic chemicals in the soil and also showed antimicrobial activity in the rhizospheric region. Also, application of nano-biofertilizers enhances the production of stress related metabolites, production of plant hormones. So, all these changes make plant to tolerate various adverse conditions and under unfavourable environmental

conditions crop plants may be established well.

Future perspectives and constraints of nano-biofertilizers

Till date limited research work is done on the development and application of nano-biofertilizers. Therefore, there is a need of proper formulation of appropriate biofertilizer microbes with specific nanoparticles. The recommendations of nano-biofertilizers for the future are as follows:

- There is a need to use advanced scientific protocols and equipments for nano-biofertilizer formulations which improve shelf-life, quality and they should be low cost and easy to use.
- Studies should be carried out to determine any adverse effects on human health.
- Multifarious nano-biofertilizers should be formulated to develop an eco-friendly and environmentally sustainable way for improving agricultural productivity.
- The compatibility of nano-biofertilizers in various types of environments and soils should be tested.
- Industry should go for large scale production along with field trials.
- Farmers should be aware about the harmful effects of chemical fertilizers and advantages of nano-biofertilizers.
- Finally, cost/benefit studies should be required for the real economic improvement of the

use of nano-biofertilizers.

SUMMARY

Sustainable agricultural intensification and climate change mitigation are the two major aspects to establish a suitable crop production framework. But the scenario of the last few decades shows that inappropriate use of inorganic/synthetic fertilizers is adversely affecting the living system and environment. Thus, adopting modern technology in agriculture will always be appreciated. Nano-fertilizers have shown great potential as an innovative approach to maintain the secure agricultural practice as well as considering the harmful aspects of the environment. However, for utilizing the long-term benefits of nano-fertilizers, detailed scientific toxicity assessments are required to know the exact depiction of environmental consequences. In that case, besides laboratory-based applications, more field-based applications under the natural environment can endeavor to acknowledge the possible relation between nano-assisted fertilizers and corresponding plant responses. Mass research work on improved synthesis and a wide range of inhabiting and remediation databases is highly desirable to create a suitable base platform for nano-fertilizers in the future smart agriculture world.

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