*Research Article……….*

International Journal of Agricultural Invention

(online available at www.agriinventionjournal.com)

*International Journal of Agricultural Invention* 8(1): 16-21: June, 2023

ISSN: 2456 – 1797 (P)

# Global trends in the use of Nanofertilizers: An intelligent technology for sustainable agriculture

***Neelesh Kapoor[1], Ankit Agrawal[1], Pankaj Chauhan[1], R. S. Sengar[1], Rekha Dixit[2]**

[1]Division of Plant Biotechnology, College of Biotechnology, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, UP, India

[2]Division of Microbial and Environmental Biotechnology, College of Biotechnology, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, UP, India

***Corresponding email**: *neeleshkapoor@svpuat.edu.in*

**ARTICLE INFO**

**Research Article**
Received on February 05, 2023
Revised on February 12, 2023
Accepted on March 07, 2023
Published on April 04, 2023

**Article Authors**
Neelesh Kapoor, Ankit Agrawal, Pankaj Chauhan, R. S. Sengar, Rekha Dixit

**Corresponding Author Email**
*neeleshkapoor@svpuat.edu.in*

**PUBLICATION INFO**
International Journal of Agricultural Invention (IJAI)
**RNI:** UPENG/2016/70091
**ISSN:** 2456-1797 (P)
**Vol.:** 8, **Issue:** 1, **Pages:** 16-21
**Journal Homepage URL**
*http://agriinventionjournal.com/*
**DOI:** 10.46492/IJAI/2023.8.1.3

**ABSTRACT**

Today's largest and oldest agricultural industry faces multiple problems. There is no doubt that the huge increase in world food production is one cause of the increased use of inorganic fertilizers which is increasing the cost involved in food production and agriculture. The use of low-quality and less efficient synthetic fertilizers has only resulted in significant environmental risks, such as: contamination of soils and water bodies. Compared to other farming systems, this is a hard truth for the world's cereal-based farming systems. Recently, healthier options have been developed through the use of nanotechnology. The advancement of nanotechnology has improved ways of large-scale production of physiologically important metal nanoparticles, which are now used to improve fertilizer formulations to increase nutrient uptake by plant cells and minimize nutrient loss. Nanofertilizers are more effective compared to chemical fertilizers due to their cost-effective, eco-friendly, non-toxic, and more stable nature. Nanostructured fertilizers can increase nutrient use efficiency through mechanisms such as targeted delivery, slow or controlled release. They could precisely release their active ingredients in response to environmental triggers and biological demands. However, the synthesis of nanofertilizers through chemical or physical methods is very expensive, so a new approach has been developed which is also known as green or biogenic synthesis. This method uses the secondary metabolites present in the plant extract that help reduce bulk material in the form of nanoparticles. Various nanofertilizers such as nano-urea, nano-zinc, nano-potassium, nano-chitosan and nano-silica have been used to deliver the micro and macro nutrients inside the plant cell efficiently. In this way, nanofertilizers can enhance crop productivity by improving seed germination rate, seedling growth, photosynthetic activity, nitrogen metabolism, and carbohydrate and protein synthesis.

**KEYWORDS**

Nanofertilizers, Nutrient Uptake, Crop Improvement, Targeted Delivery, Biogenic

**HOW TO CITE THIS ARTICLE**

Kapoor, N., Agrawal, A., Chauhan, P., Sengar, R. S., Dixit, R. (2023) Global trends in the use of Nanofertilizers: An intelligent technology for sustainable agriculture, *International Journal of Agricultural Invention*, 8(1): 16-21. DOI: 10.46492/IJAI/2023.8.1.3

Fertilizers are chemical compounds applied to promote plant growth and yield (Behera and Panda, 2009). Fertilizers are usually applied either through the soil or by foliar spray. The inorganic fertilizers are artificially synthesized and are formulated in appropriate concentrations and the combinations that usually supply three main nutrients: nitrogen, phosphorus and potassium (N, P, and K) for various crops and growing conditions. Nitrogen promotes leaf growth and forms proteins and chlorophyll. Phosphorus contributes to root, flower and fruit development. Potassium contributes to stem and root growth and the synthesis of proteins (Mandal *et al*., 2009).

About 30–60% of N, 10–20% P and 30–50% K of the applied dose is utilized by plants and the rest is lost to the environment. This causes substantial economic and resource loss as well as serious soil and water contamination. These problems have initiated repeated use of fertilizer which adversely affects the inherent nutrient balance of the soil. With the application of nanotechnology, these demerits of conventional fertilizers can be minimized, so as to utilize the major proportion of the applied dose of the chemical. This can be achieved by encapsulating the nutrients by nanomaterials, coated with a thin protective film, or delivered as emulsions or nanoparticles (De-la-Rosa *et al.,* 2010).

## Nanofertilizers

Nanofertilizer technology is very innovative and scanty reports in scientific journals are available. Researchers are creating new nano particles to provide us with nutrients. In the sense that nano technology has considerable surface area, it is capable of storing various types of nutrients in plentiful quantities for long duration without any relevant side effects of customized inputs (Preetha and Balakrishnan, 2017). These nanofertilizers can solve the main problem of high nutrient losses in the soil by allowing the slow and sustained release of nutrients over an extended period (Seleiman *et al.,* 2021).

## Formulation and Characteristics of Nanofertilizers

The formulation of any nano-fertilizer should be in such a way that they possess all desired properties such as high solubility, stability, effectiveness, time-controlled release, enhanced targeted activity with effective concentration and less eco-toxicity with safe, easy mode of delivery and disposal (Green and Beestman, 2007, Torney *et al.,* 2007). So, nanofertilizers 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 help of nanotechnology used to improve soil fertility, productivity and quality of agricultural produces. Nanoparticles can make from fully bulk materials.

To prevent wastage of fertilizer, reduce the dose, and increase efficiency, the fertilizer can be coated, binded or encapsulated by some specific nanomaterials. Coating and binding of nano and sub Nano-composites help to regulate the release of nutrients from the fertilizer capsule (Liu *et al.,* 2001). Nanoparticles have great potential to deliver nutrients to specific target sites in living systems. The loading of nutrients on the nanoparticles is usually done by: absorption on nanoparticles, attachment on nanoparticles mediated by ligands, encapsulation in nanoparticulate polymeric shell, entrapment of polymeric nanoparticles and synthesis of nanoparticles composed of the nutrient itself.

## Penetration and Translocation of Nanofertilizer

The application of nanofertilizer is promising and efficient translocation of nutrients to the desired parts of plant (Deepa *et al.,* 2015). Nanoparticles aggregate with diameter less than the pore size of plant cell wall which can easily enter through the cell wall and reach up to the plasma membrane (Moore, 2006, Navarro *et al*., 2008). Engineered nanoparticles can penetrate the stomatal pores with the size of less than 50 nm as observed by (Eichert *et al.,* 2008) in *Vicia faba* L. The applied nanoparticles get transported from the site of application to the heterotrophic cells, which carried via the phloem vessels likely through the plasmadesmata (Knoblauch and Oparka, 2012, Etxeberria *et al.,* 2016). Nanoparticles can also be transported into the plant by forming complexes with membrane transporters (Kurepa *et al.,* 2010). Once the nanoparticle gets entered into the plant system which may be transported form one cell to other cell through plasmodesmata and carried by aquaporins, ion channels, endocytosis or by binding to organic chemicals (Rico *et al.,* 2011).

## Polymer based Release of Nanofertilizers

Polymer helps to release the nutrients in a controlled manner; this can be useful in the production of polymer coated nanofertilizer as smart fertilizer (Manjunatha *et al.,* 2016). Polymeric nanoparticles have a matrix architecture composed of biodegradable and biocompatible polymers of synthetic or natural origin. Among the various natural polymers, alginate, albumin or chitosan have been widely explored.

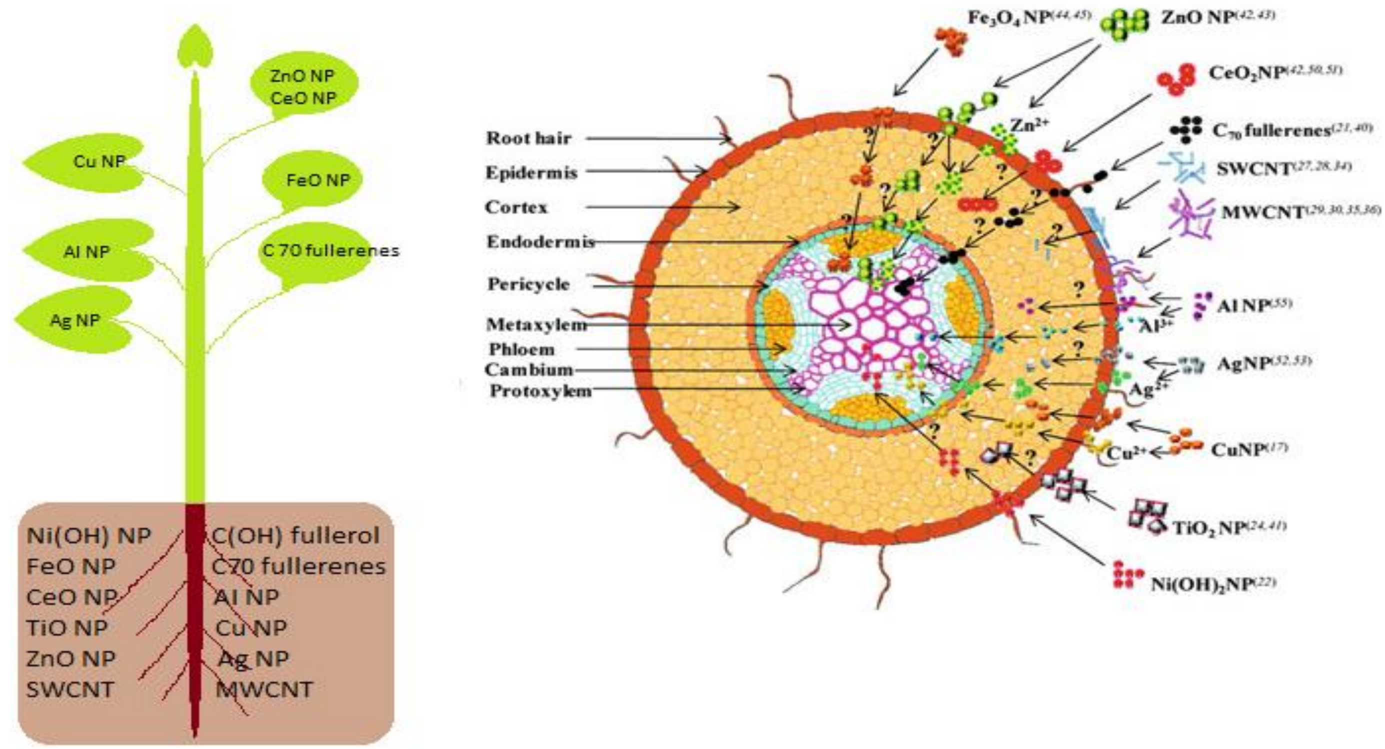


**Fig 1. Uptake, translocation and biotransformation pathway of various nanoparticles in a plant system**

The biodegradable, polymeric chitosan nanoparticles with the size of 78 nm were used for the controlled release of NPK fertilizer (Corradini *et al.*, 2010). Sharmila and Rahale (2011) reported that nano-clay based fertilizers released the nutrient for a long period of time than conventional fertilizer.

## Types of Nanofertilizers

### Nitrogen Nanofertilizer

The 50–70% of the nitrogen applied using conventional fertilizers is lost to the soil due to leaching and lower nitrogen utilization efficiency (NUE) by plants. Attempts to increase the NUE in conventional fertilizer formulations have not been much effective. Overcoming problems connected with nitrogen leaching during application of fertilizers, researchers tested various coating materials including polyurethane resin-coated urea, neem coated urea, sulphur coated urea. Slow-release fertilizers are too costly and it takes more time to release nitrogen. On the other hand, the emerging nano strategies indicate that, due to the high surface area to volume ratio, nano nitrogen is expected to be far more effective than even conventional coated nitrogen fertilizers (Hossain *et al.*, 2008, De-Rosa *et al.*, 2010).

The use of zeolite would boost crop production in an outstanding way. Clinoptilolite zeolite (CZ), a porous mineral with a high CEC and great affinity for ammonia, was used by Chinese researchers to minimize ammonia emissions from manure and also to reduce ammonia toxicity to plants. The amendment of clinoptilolite zeolite (CZ) to sandy soil resulted in lowering $NO_3$ - and $NH_4$ - concentrations in the leachate and to increasing of moisture retention in the soil (Agger, 2003).

### Phosphorus Nanofertilizer

Generally, commercially available P fertilizers such as MAP (mono ammonium phosphate), DAP (diammonium phosphate) or TSP (triple superphosphate) are water soluble phosphate salts and thus, are regarded as high quality fertilizers. However, these soluble phosphates are also very mobile in the soil and large portion often ends up in surface-water bodies through runoff or seepage, causing eutrophication. For these limitations, the nano-sized apatite particles could be as effective in providing the nutrient phosphorus as the commonly used soluble phosphorus fertilizers, and shall also minimize the eutrophication and the delivery problem associated with the later.

Rather, application of nano-sized solid phosphorus as fertilizer would be a good compromise between agricultural benefits and the environmental hazards. It had been found that the phosphorus nanoparticle suspension and an aqueous solution of phosphorus have same mobility rate in the soil columns. The phosphorus nanoparticles can be easily delivered to the root zones with conventional methods like spray or irrigation. Moreover, the nanoparticles are environmentally benign because the phosphorus in solid form is much less bioavailable to the algae than those in soluble forms (Reynolds and Davies, 2001).

**Potassium Nanofertilizer**

Plants deficient in potassium are susceptible to drought, high temperature and excess water. They are less susceptible to pest, pathogen and nematode attacks. Some natural zeolites contain a considerable amount of exchangeable potassium that enhances plant growth. It is suggested that slow and steady release of K from zeolites has the benefits of providing plant roots with additional nutrients at the same time. A research showed that the equilibrium K concentration increased with the increase in potassium sorbed on zeolite. Li *et al.* (2010) studied a slow-release fertilizer composed of potassium-loaded zeolite (K-Z) in hotsauce peppers as an example. Without depending on chemical fertilizers, nanotechnology can help to further increase the abundance of potassium in soil.

**Zinc Nanofertilizer**

Researchers have ascertained that water-soluble zinc is the major parameter controlling the effectiveness of Zn-enriched fertilizers for plant growth and development (Gangloff *et al.,* 2002). The ZnO is a most commonly used Zn fertilizer which is applied to the crops in Zn-deficient regions. Application of ZnO NPs as a source of Zn in Zn fertilizers may improve the efficiency of the fertilizer and Zn availability to plants by enhancing the rate and extent of Zn dissolution. The Zn NPs may be applied as a foliar spray. This treatment may potentially enhance uptake and the penetration of zinc oxide nanoparticles in the plant leaves. Pot studies with foliar spray have demonstrated that plants sprayed with ZnO NPs solution showed improved growth and biomass production over control plants (Panwar *et al.*, 2012, de-la-Rosa *et al*., 2013).

**Achievements or Applications of Nanofertilizers**

Nano fertilizers providing greater role in crop production and several research study revealed that nanofertilizers enhanced growth, yield and quality parameters of the crop which result better yield and quality food product for human and animal consumption.

| **Stressful Plant** | **Applied** |
|---|---|
| ↓ | ↓ |
| Increase Protein Damage | High Plant Biomass |
| Increase DNA Damage | High Pigment Contents |
| Increase Oxidative Stress | High Crop Quality |
| Altered Gene Expression | High Photosynthetic Rate |
| Altered Enzyme Activities | High Protein Contents |

**Seeds Germination and Growth Parameters of the Plant**

Nano fertilizers can easily penetrate into the seed and increase availability of nutrient to the growing seedling which result healthy and more shoot length and root length but if concentration is more than the optimum it may show inhibitory effects on the germination and seedling growth of the plant. Nano ZnO recorded higher peanut seeds germination percent and root growth compare to bulk zinc sulphate (Prasad *et al.,* 2012). Similarly positive effective of nano-scale $SiO_2$ and $TiO_2$ on germination was reported in soya bean (Liu *et al.,* 2005). Nano fertilizers increase availability of nutrient to the growing plant which increase chlorophyll formation, photosynthesis rate, dry matter production and result improve overall growth of the plant (Mahajan *et al.*, 2013).

**Yield**

Foliar applications of nanofertilizer had reflected in improvement in yield parameters of wheat plants (Abdel-Aziz *et al.,* 2018). Foliar spray of NPK nanofertilizers in chickpea increased the yield and yield components as a result of increased growth hormone activity and enhancement of metabolic process, tended to increase in flowering and grain formation (Drostkar *et al.*, 2016).

Application of nanofertilizers have greater role in enhancing cotton yield production besides reducing the cost of fertilizer and also minimizing the pollution hazard. Significant increases of total and open bolls per plant, boll weight and seed cotton yield with the foliar nanofertilizers application than soil application (Sohair *et al.*, 2018).

## Conclusion and Future Prospects

Nanotechnology provides new agrochemicals and delivery tools to improve crop productivity, and it promises to reduce doses of chemicals. Development and application of nanofertilizers is one of the potentially effective options of enhancing the global agricultural productions and reducing the chemical inputs. Application of nanotechnology in the direction of reduction in the dose of agrochemicals through coating, encapsulation, etc. may greatly minimize the adverse effects of synthetic chemicals on crop production. However, coating, encapsulation, nano-emulsions are in the developing stage, and it is probably a long way in reaching nano-products in the farms in developing and underdeveloped countries.

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