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Nano-Technology is a Novel Approach for Nutrient Management

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Abstract

Nano-technology emerges as a groundbreaking approach for nutrient management, presenting innovative solutions to enhance the efficiency and sustainability of nutrient utilization. By leveraging the unique properties and behaviour of nanoparticles, nano-technology offers unprecedented control over nutrient delivery and utilization in diverse fields such as agriculture, wastewater treatment, and aquaculture. Nano-fertilizers and nano-pesticides enable targeted and precise delivery of nutrients to plants, improving their absorption and minimizing environmental losses. Furthermore, nano sensors and nano biosensors provide real-time monitoring of soil nutrient levels, enabling optimized and timely application of fertilizers. The application of nano-engineered materials in wastewater treatment and aquaculture aids in removing excess nutrients meanwhile promoting the health of ecosystems. Despite the need for careful consideration of safety aspects, nano-technology exhibits immense potential in revolutionizing nutrient management practices and paving the way for a more sustainable future.

Key words: Nano-particles (NPs), Nan0 fertilizers, soil health and Nutrient management

Introduction

India's socio-economic development depends heavily on agriculture; hence the productive agriculture sector is crucial to the nation's economy. A strong agriculture sector always boosts the economy since every 1% increase in per-capita agricultural growth results

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in 1.5% increases in non-agricultural growth (Aravinth *et al.,*2022). Agriculture today is faced with demands for greater efficiency in food production due to a growing population and a shrinking arable land base and water resources. The distribution of per-capita land per hectare in India currently places it at position 104th in the globe and the situation is worrying (Yaqoob *et al.,*2022). Technical innovation is crucial in agriculture in order to meet global concerns such as population expansion, climate change, and the finite availability of essential plant nutrients. Fertilizers are crucial because they increase agricultural productivity by 35-40%. Due to the limited availability of water and arable land, it is necessary to boost the resource efficiency and reduce agro-ecological damage by employing modern technologies like nanotechnology (Manjunatha *et al.* 2016).

The term "nanotechnology" is derived from the word's "nano" and "technology." The word "Nano" originates from the greek word "Nanos," which meaning "dwarf." The words "technology" and "logos" originate from two greek words that mean "manmade" and "language," respectively. Nano science and nanotechnology are fundamentally distinct, since the former is the science of studying materials at the nanoscale, while the latter is the application of that knowledge across many disciplines. Nanotechnology encompasses a range of technologies related to the manipulation of matter at the length scale of 1–100 nm. Particles on the scale of less than 100 nm fall in a transitional zone between individual atoms or molecules and corresponding bulk material, which can lead to dramatic modifications in the physical and chemical properties of the material. Nanotechnology has already led to many innovations in fields as varied as medicine, material science, and electronics. Furthermore, nanotechnology is ubiquitous in our consumer products from textiles, to sports equipment, to electronics. Clear prospects exist for impacting agricultural productivity through the use of nanotechnology. Nano fertilizers are one potential output that could be a major innovation for agriculture; the large surface area and small size of the nanomaterials could allow for enhanced interaction and efficient uptake of nutrients for crop fertilization (DeRosa *et al.* 2010). The integration of nanotechnology in fertilizer products may improve release profiles and increase uptake efficiency, leading to significant economic and environmental benefits.

Nano fertilizer on crop production is a developing field, and various NPs have been successfully used as macro and micro nutrients to improve soil fertility, nutrient uptake by plants, and ultimately, crop productivity. However, the toxic effects of NPs in soil, crops, and water and their surpassing in the food chain are major topics that need research. Nano-nutrients, nano-pesticides, insect repellents, nano-sensors, nano-magnets, nano-films, nano-filters, and other nanotechnology assisted applications have the potential to alter agricultural productivity and allow improved input management. This book chapter gives a detailed discussion on role and mechanism of various NPs as plant nutrients in improving soil health, fertility and production.

Nano fertilizers and their Classification

Nano fertilizer

In order to establish soil fertility, productivity, and the quality of agricultural products, nano fertilizers are made from conventional fertilizer, bulky fertilizer materials, or extracted from plant parts or different plants by coating them with nanomaterials (Zulfiqar *et al.,* 2019). The combined nutrients can be released in nano sized form in a controlled manner to improve the efficiency of crop plants along with the minimum impact on the environment. The use of nano-fertilizers in a correct way can feed plants slowly in such a manner that increases the nutrient use efficiency, prevents leaching, minimizes volatilization and diminishes overall environmental risks. Nano fertilizers improves the bioavailability of nutrients owing to the high specific surface area, mini size and more reactivity (Solanki *et al*., 2015).

The encapsulation of nutrients with nanomaterials can be done in the following ways (Iqbal 2019)

- Entrapped within the nanomaterials
- Coated with a layer of nanomaterials
- Delivered in the form of nano-emulsions

Types of Nano fertilizer

Nano-fertilizers have been classified into three groups

a. Nano formulation of macronutrients
b. Nano formulation of micronutrients
c. Nutrients-loaded nanomaterials

a. Nano formulation of macronutrients

This classification includes all the primary and secondary elements for identifying as a label of nano fertilizer.

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- **Nitrogen nano fertilizer** – Zeolite-based nitrogen nano fertilizer indicates higher accumulation of N with reduced leaching and volatilized losses of N and exhibition of better soil pH, moisture (Rajonee *et al.,* 2016).
- Phosphorus nano fertilizer – The use of nano hydroxy apatite nano fertilizer enhance crop growth and seed yield and chemical contents in plants, as well as encapsulated biodegradable P, found that it can be accumulated through leaves which eliminates the requirement of P bonding in the soil (Soliman *et al*., 2016).
- **Potassium nano fertilizer** – Application of 150 ppm Nano-K is most effective in increasing the leaf area with no. of leaves, harvest index, grain yield, biological yield, K percentage, disease and pest resistance and chlorophyll content (Giardini 2016).
- **Calcium nano fertilizer** – Spraying of 500 mg/L of Nano calcium significantly reduces fruit cracking with improvement in fruit quality and quantity and also influences the increase in no. of flowers (Seyd mohammad 2020).
- **Magnesium nano fertilizer** – Concentration of 500 ppm of Magnesium hydroxide nano fertilizer gives an improvement in growth and development with 100% seed germination (Shinde *et al.,* 2018).
- **Sulfur nano fertilizer** – Applying sulfur nano fertilizer to the soil enhances sulfur metabolism and limits the deleterious effects of Mn stress (Ragab and Saad-allah 2020)

b. Nano formulation of micronutrients

- **Iron nano fertilizer** – Iron chelated nano fertilizer is highly stable and provides a slow release of iron in the abroad pH range. Application of iron oxide nano fertilizer at a concentration of 30µM significantly increase growth parameter, photosynthetic pigments and total protein content (Askary *et al.,* 2017).
- **Zinc nano fertilizer** – Out of all method, the seed priming method of application of zinc nano fertilizer (≤100 mg/kg) efficiently enhance Zn uptake, chlorophyll content with increased no. of leaves flowers and lateral branches (Seyd mohammad *et al.,* 2020, Sharifi *et al.,* 2016).
- **Copper nano fertilizer** – Application of biosynthesized copper nano fertilizer at doses up to 20µg/mL improved mitotic index in dividing cells, improvement in stress tolerance, improves the level of protein in starch degradation and increases root length, etc. (Yasmen *et al.,* 2017).

- **Manganese nano fertilizer –** By using 0.05 mg/L lengthen the roots and shoots and improve the photosynthesis process with increase fresh and dry biomass and causing improved salt tolerance in crops (Preetha and Balakrishnan, 2017).
- **Boron nano fertilizer –** at 90mg/L concentration of boron nano fertilizer indicated increased plant height, no. of pods total seed yield and forage quality in calcareous condition (Ibrahim and Taherian *et al.,* 2019).

c. Biofertilizers-Based Nano fertilizer

Biofertilizer-based nano fertilizer is the coexistence of biocompatible nanomaterial and biological sources which focus on slow and gradual nutrient release over a long span for promoting crop yield and productivity (Duhan *et al.,* 2017). Nanocarriers ensure the long-range availability of fertilizers at different stages of plant growth. It betters the field performance and reduces the economic expenditure. The PGPR is beneficial for soil nutrient content via nitrogen fixation, formation of siderophores and phosphate solubilization (Thirugananasambandan, 2019).

Manufacturing of Nano fertilizers

Nano fertilizers can be prepared by different approaches:

1. Physical (top-down)
2. Chemical (bottom-up)
3. Biological (biosynthesis of natural source)

Physical (top-down)

The "top-down" method requires breaking down solid materials into little bits using external force. Many physical, chemical, and thermal processes are utilised in this strategy to produce the energy required for nanoparticle production. The second method, referred as "bottom-up," involves gathering and merging gas or liquid atoms or molecules. Due to cavities and roughness that can arise in nanoparticles, it is hard to get ideal surfaces and edges in the top-down technique, which is a costly method; nevertheless, good nanoparticle synthesis outcomes can be obtained in the bottom-up approach. Furthermore, the bottom-up process produces no waste materials that must be eliminated, and nanoparticles with smaller sizes may be created owing to improved control of nanoparticle sizes (Turgut *et al.* 2021).

Chemical (bottom-up)

Some of the most often used chemical techniques for NPs synthesis include the sol-gel method, microemulsion technique, hydrothermal synthesis, polyol synthesis, chemical vapour synthesis, and plasma enhanced chemical vapour deposition technique (Dhand *et al.,* 2015). Toxic chemicals are commonly used in chemical processes for metal nanoparticle manufacturing, which can be hazardous to our environment.

Biological (biosynthesis of natural source)

The biological approach, which is provided as an alternative to chemical and physical methods, is an ecologically benign method of nanoparticle synthesis. Microorganisms have now been investigated as possible bio factories for metallic nanoparticle production. The biological approach is simple and quick, usually requiring only one step and is environmentally safe. In this circumstance, we may employ microbes as well as various plant components to make nanomaterials. Different microorganisms, such as bacteria, fungus, and algae, can be employed to make various nanomaterials. The nanoparticles were also made with the help of plants and plant extracts. Phytochemicals such as flavones, organic acids, and quinones reduce metal nanoparticles, making them natural reducing agents for nanoparticle synthesis (Kolahalam *et al.,* 2019).

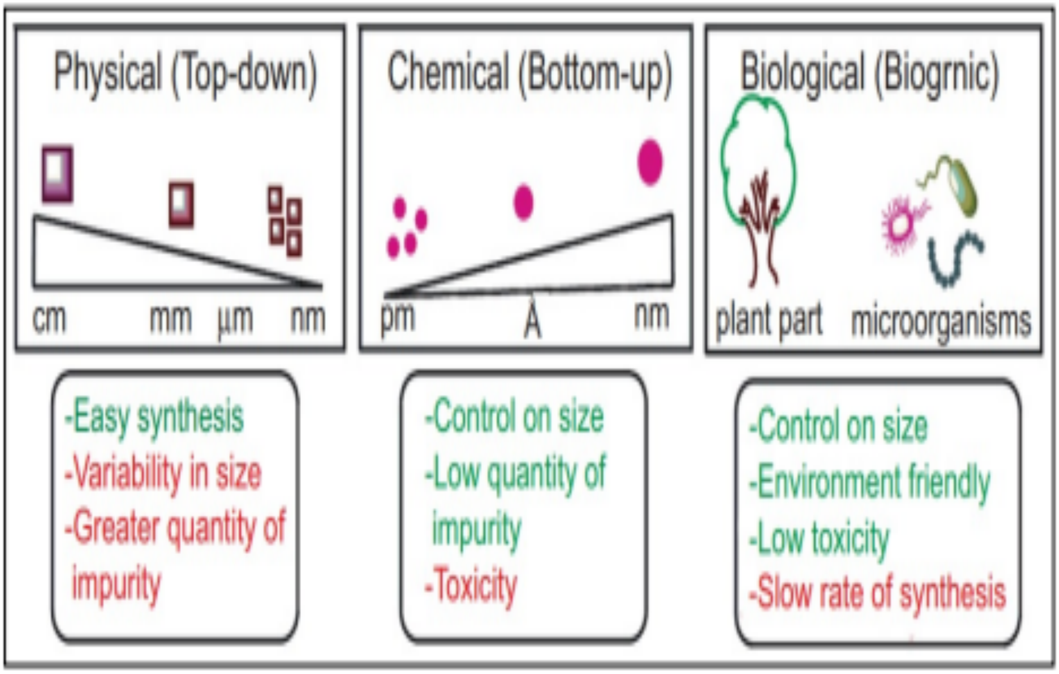

Fig 1: Methods for making nanofertilizers are depicted in this diagram (Zulfiqar *et al.,* 2019).

Methods of application of nano fertilizers

- **Soil application: -** Most frequent technique of nutrient supplementation using chemical and organic fertilizers is soil application. When choosing this method of fertilizer distribution, consider the amount of time the fertilizer that will remain in the soil, soil texture, soil salinity, plant sensitivity to salts, salt concentration, pH of amendment. It is generally known that negative soil particles affect mineral nutrient adsorption. When compared to cation exchange capacity, most agricultural soils have a low anion exchange capacity. Nitrate, the most mobile of the anions in the soil solution, is susceptible to leaching by water moving through the soil. Because the positively charged Fe^{2+}, Fe^{3+} and Al^{3+} have an OH group that exchanges with phosphate, phosphate ions bind to soil particles carrying aluminum or iron. As a result, phosphate's mobility and availability in soil may be severely restricted (Taiz and Zeiger, 2010).
- **Foliar application: -** Liquid fertilizers are sprayed directly onto the leaves in this approach. It is commonly used to provide trace elements. During the rapid development period, foliar spray can shorten the time between application and plant uptake. It can also solve the problem of limited nitrogen uptake from the soil. When compared to soil application, where iron, manganese and copper are adsorbed on soil particles and thus less available to the root system, this method may be more efficient (Taiz and Zeiger 2010).

Mode of action and chemistry of nano fertilizers

The application of mineral fertilizer in excess has a huge impact on soil and groundwater. Excess minerals get leached down in soil or contribute to air harming sustainability and crop production (Chandini *et al.,* 2019). Nano fertilizers being ecofriendly are one of the alternatives to mineral fertilizers, capable to increase soil fertility, improve yield, reduce pollution and increase microbial activities (Ahmed *et al.,* 2012). Nanotechnology can be considered as a powerful solution in the agriculture sector to increase the efficiency of fertilizers and pesticides, reduce pollution and is also used in food processing technology (Baruah and Dutta, 2009). Nano-fertilizers provide control release of agrochemicals, reduce toxicity in soil and plant, site targeted delivery as well as maximize nutrient efficiencies of the utilized fertilizer (*Cui et al.,* 2010).

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- **Maximization of Nano fertilizers Efficiency-** The nutrient use efficiency in agriculture is 20-50% for N, 10-25%for P and 30-40% for K fertilizers. It indicates the need for food production to be much more efficient (Tarafdar *et al.,* 2013). Fertilizers that are typified in nano-particles have increased accessibility and uptake of nutrients. The utilization of nano-fertilizers has a positive effect on the effectiveness of fertilizers and supplements uptake by plants from soil (Liscano *et al.,* 2000).
- **Control of Nutrients Release-** About 40-70% of nitrogen, 80-90% of phosphorus, and 50-90% of potassium fertilizers are lost within the soil and don't reach the plant (Saigusa, 2000). More fertilizers and pesticides will be applied to the soil to compensate for the fertilizer lost. It will affect the balance of nutrients adversely. Nano-fertilizers are one of the ways to overcome the problem of excessive use of fertilizers. Slowly-released nano fertilizer s can be considered a great alternative to traditional fertilizers. They provide a moderate rate of discharge of supplements during the development of crops. Plants can absorb most of the nutrients without much loss (Huiyuan *et al.,* 2018). Nano-particles strongly bond the nutrients when fertilizer is coated on the surface of nanomaterials because of their higher surface tension than that of conventional fertilizers. This coating increases the efficiency of fertilizers by controlling the release of these fertilizers (Brady and Weil, 1999). Nitrogen fertilizer is very important but because of its high solubility nature, it causes severe damage to the plants and surroundings.

Application of nanotechnology in crop nutrient management

Conventionally applied fertilizers lose around 40-70 percent nitrogen, 80-90 percent phosphorus and 50-90 percent potassium in the environment, necessitating recurrent fertilizer treatments. Silver, zinc, iron, titanium, phosphorus, molybdenum and polymer nanoparticles are examples of nano fertilizers that have showed tremendous promise in crop development (Chhipa, 2019). Nano encapsulation is a method of releasing substances such as fertilizer slowly but effectively into a plant's root zone for optimum nutrient absorption. Diffusion, dissolution, biodegradation, and osmotic pressure with a certain pH are some of the nanoencapsulation release processes (Ding and Shah, 2009; Vidhya lakshmi *et al.*, 2009).

Higher nutrient use efficiencies and yields

Nano fertilizers increases various growth parameters like height of plant, area of leaf, number of leaves, green matter synthesis, production of chlorophyll and photosynthetic rate which results higher yield when compared to traditional fertilizers. According to Cui *et al.* (2010) nanostructured formulations are able to increase fertilizer efficiency and nutrient absorption ratios for production of crops while also conserving fertilizer resources and also investigated that leaching of fertilizer nutrients into soil can be reduced with nanostructured formulations. Encapsulation in envelope forms comprising semipermeable membranes coated with resin-polymer, waxes and sulphur might accurately control both the rate and pattern of nutrient release for water soluble fertilizers. W heat growth parameters, yield parameters and yield were improved by foliar application of crop with combination of N, P and K nano-fertilizers at lower concentrations (Abdel-Aziz *et al.,* 2016). Even in the most difficult environments, nanotechnology has the potential to boost agricultural production while remaining environmentally friendly (Sugunan and Dutta, 2008). According to Pour Jafar *et al.* (2016) the use of foliar sprays of nano micronutrients (iron and manganese) boosted canola grain output, plants treated with iron sulphate 1 per thousand + manganese sulphate 1.5 per thousand produced the highest grain production.

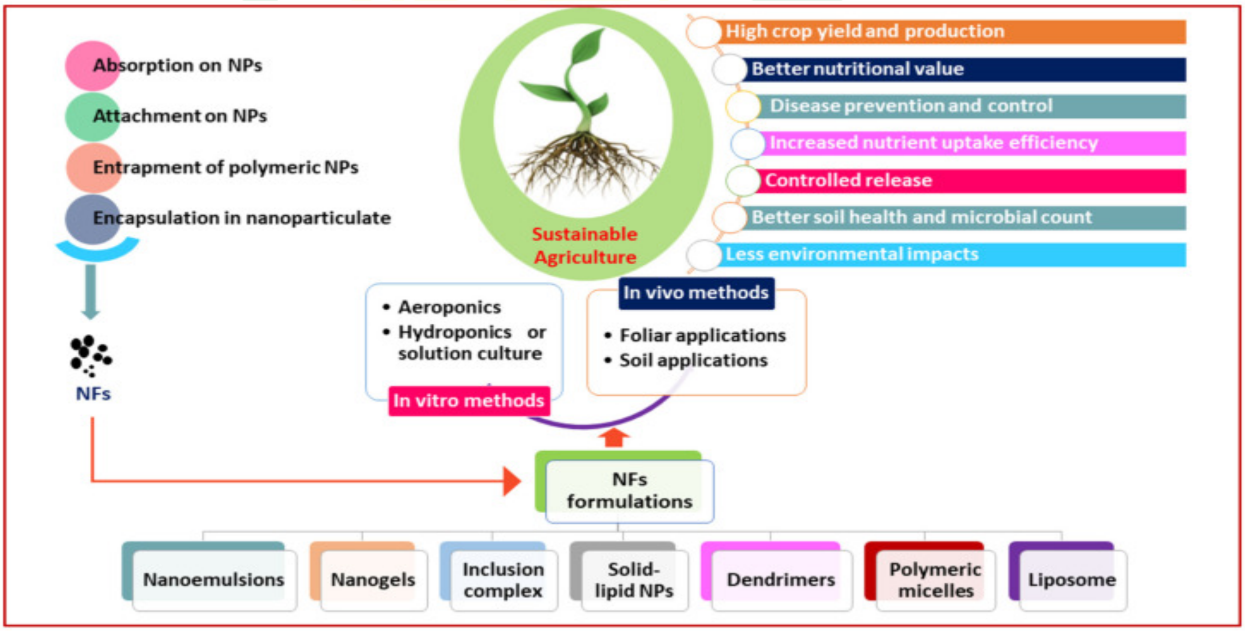

Fig 2: An overview of nano-fertilizer application in agriculture. NPs = nano-particles; NFs = nano-fertilizers (Verma *et al.*,2022)

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Advantages and dis advantages of nanotechnology

Advantages

Agriculture an efficient as nanotechnology improves yields and product quality, increasing nutritional benefits.

- Accurately distribute micronutrients to the appropriate portion of the body at the correct time.
- Fertilizers in agricultural formulations on the nanoscale can improve efficiency and reduce environmental losses.
- Nano fertilizers administered in much smaller amounts, therefore lowers transportation cost, eases and boosting application.
- Apart from boosting stress tolerance, it improves seed germination, seedling development, photosynthesis, nitrogen metabolism, and protein and carbohydrate synthesis
- Because of the high reactivity of nanomaterials, their interaction with fertilizers results in enhanced and effective uptake of nutritional elements by plants.
- Salts are not deposited in the soil.
- They can be synthesised to meet the nutritional needs of the target crops.
- Biosensors may be linked to a new novel fertilizer that regulates nutrient supply based on soil nutrient status, crop development phase, and ambient conditions.

Disadvantages

- Plants have a tendency to absorb non-essential components in addition to necessary elements, which, if aggregated over a certain threshold level, might be fatal to non-tolerant species.
- Unavoidable release of a significant number of nanoparticles into the environment during manufacture and application, posing a hazard to geo and hydrosphere living creatures
- There are no clear rules on the manufacture, labelling, or disposal of nanoparticles anywhere in the world, compounding potential human and environmental health and safety concerns related with nanotechnology.

- There has been little research on the accumulation of NPs in edible sections of plants and the bioavailability of those NPs to the next trophic level.

Conclusion

For feeding increasing population it has become necessary to increase the agricultural production without deteriorating the health of ecosystem. Higher use of fertilizers chemicals also causing several issues related to the environmental degradation, soil health depletion and pollution. Sustainable agriculture is the key to the address such type of issues. Nano techniques in agriculture could help us to attain the sustainable goals by decreasing the input levels, costs and thereby increasing the efficiencies and decreasing the environmental pollution and toxicities caused due to overuse of these chemicals and fertilizers. Newer dimensions of agriculture like precision agriculture, integrated nutrient management, nano sensing can be enhanced by using the nano techniques in agriculture.

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