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Nanofertilizers: A Review on the Futuristic Technology of Nutrient Management in Agriculture

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ABSTRACT

Nanofertilizers have recently gained popularity in agriculture for increasing crop production, improving nutrient usage efficiency and lowering chemical fertilizer waste and cultivation costs. Current challenges in the agriculture like low nutrient use efficiency, increasing contamination and pollution due to the overuse of chemicals and fertilizers, decreasing soil microflora and deteriorating soil health can be tackled effectively with innovations in agriculture like use of nano techniques. Among the nano technique, nano fertilizers are emerging as potential tool for the nutrient management. Nanofertilizer technique finds its immense scope in the precision agriculture where the nutrients are applied at specific location preventing the wastage of fertilizers. Several researchers have found that the nanofertilizers usage in the agriculture increases crop yield, decreases nutrient losses, decreases the chances of diseases by avoiding overfertilization, improves the soil and environmental health. Foliar application of the nanofertillzers also improved the nutrient uptake. Nanofertilizers improves the surface area available for various metabolic reactions in the plant system, resulting in a faster rate of photosynthesis and higher crop dry matter and yield. Even in difficult soil and weather circumstances, foliar spraying can be done. Furthermore, it facilitates direct nutrient absorption utilization efficiency (NUE) and a rapid response to crop development.

Key words: Growth, IFFCO, Limitations, Nanofertilizers, Nutrient use efficiency, Pollution, Yield.

Increasing human population is putting tremendous pressure on the agriculture and the allied sectors. The demand of food is supposed to increase approximately 59-98% between 2005 and 2050 which is higher than the Food and Agriculture Organisation projection of 54% from 2005/2007. The increase in the use of the fertilizers and other agrochemicals for increasing the agriculture production is also leading to the increase in problems related to environmental degradation as well as groundwater pollution leading to deterioration of the water bodies and their qualities. Moreover, the availability of nutrients from these fertilizers to plants is low. As indicated by Subramanian *et al.* (2015) the use efficiency of N, P and K stand still at 30-35%, 18-20% and 35-49% individually. Nano technologies are emerging as a powerful tool in the numerous sectors like pharmaceutical sector, particles sectors and others. It is also emerging as a powerful technique in the agriculture for fertilization. The word “nano” means 10^{-9} or one billionth part of a meter. “Nanoparticles are particles with at least one dimension of fewer than 100 nanometers” (Thakkar *et al.,* 2010). Extensive researches have been carried using nano fertilizers and other nano technologies for increasing the agricultural production. The present scope of study is to compile the various facts related with these technologies and to study the various prospects associated with it.

Why Nano fertilizers?

Lesser bulkiness

Nano fertilizers provide very higher specific area to the volume. Fig 1 provides the comparison of the nano particles with the other particles which suggests that the bulk of the fertilizers can be reduced with the help of nano technology. Nano fertilizers are advantageous over conventional fertilization systems because the amount of the bulk can be reduced significantly. Assume the large bags of the urea fertilizers can be replaced by the single bottle of fertilizer and it will reduce the cost as well as drudgery to transport the fertilizer. The findings of 600 on-farm trials with eight crops done in different districts of Rajasthan during winter season indicated that the amount of urea sprayed by farmers to feed nitrogen to the crops may be successfully decreased to half. Most of the crops studied in these trials, yields achieved with 50 per cent less nitrogen with two sprays of nano-nitrogen in standing crops were higher than those obtained with the nitrogen applied alone with urea. The results show that nanofertilizers can greatly improve nutrient use efficiency, as demonstrated by a 50% reduction in urea consumption after just two sprays of Nano N. Nanofertilizers are seen as an innovative way to conserve nutrients,

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Fig 1: Scale of different particles and representation of nitrogen of one bag of urea to the one IFFCO nano urea bottle.

particularly nitrogen, while also safeguarding the environment (Kumar *et al*., 2020).

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 (Ail and Al-Juthery, 2017). 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. Cui *et al.* (2010) 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 (Cui *et al*., 2010). Wheat 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). When compared to ammonium sulphate, replenishing sandy soil with ammonium-loaded zeolite can reduce N leaching while maintaining sweet corn growth and enhancing N usage efficiency (Perrin *et al.,* 1998). Hernandez *et al.* (1994) demonstrated the similar result, demonstrating that combining zeolite with slow-release N fertilizers increases N efficiency. According to Pourjafar *et al.* (2016) the use of foliar sprays of nanomicronutrients (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.

Increases nutrient availability to plants

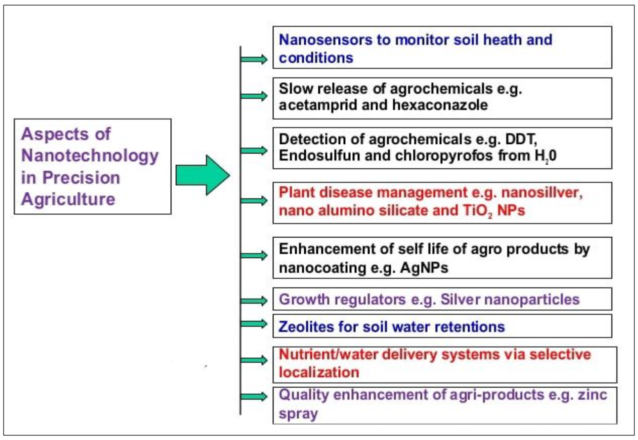
The mineral nutrients in the soil must be accessible so that the plant may easily absorb them (Barber, 1995). Nutrient availability to plants is determined by the amount, type and association of nutrients in the solid phase. It can also be defined by the capacity of the soil-plant system to supply and absorb nutrients, which includes the transfer and absorption of nutrients from the solid phase to the liquid phase (Comerford, 2005). Nanomaterial surface coatings on fertilizer particles retain the material more tightly than traditional surfaces due to higher surface tension, allowing for more controlled release (Brady and Weil, 1999). As a result of this the nutrient availability to plants is increased due to the use of nano fertilizers. Nano-fertilizers have a huge surface area and particle size that is smaller than the pore size of plant leaves, allowing them to penetrate deeper into plant tissues and improve nutrient utilization efficiency and uptake (Qureshi *et al*., 2018; Dimkpa *et al*., 2015). Gosavi *et al.* (2017) established the beneficial effects of foliar nitrogen, phosphorus and potassium on maintaining correct leaf nutrition, carbon balance and enhancing photosynthetic performance.

Precision agriculture through nano fertilizers

The precision agriculture is the need of future to combat the various problems related with the agriculture like pollution and environmental degradation. Precision agriculture through precise nano fertilizers lessens the fertilizer requirement and hence increase the fertilizer use efficiency. Also, the nano particles provide the smart delivery system for the fertilizers thus enhancing the precision and the efficiency of fertilizers. "A smart delivery system is a combination of specifically targeted, highly controlled, remotely regulated and multifunctional properties that minimize biological barriers for successful targeting" (Nair *et al*., 2010).

Controlled release of fertilizer

Burden on our natural resources has increased dramatically as a result of the massive population boom. Nitrogenous fertilizer use is increasing, resulting in lower nutrient efficiency and increasing contamination. It is now time to monitor fertilizer release, thereby improving nutrient use



efficiency and lowering pollution. Fertilizer toxicity is reduced when it is released in a controlled manner. Because of its controlled release nature, zinc oxide nano fertilizer increases root growth and percentage of germination in peanut seeds compared to bulk zinc sulphate (Li and Zhang, 2010).

Effect on seed germination and crop growth

In soybeans, nano-scale SiO_2 and TiO_2 were found to have a beneficial influence on germination (Mahmoodzadeh *et al*., 2013). Nano-fertilizers enhances availability of nutrients for growth of plants, also results in increased chlorophyll formation, photosynthetic rate and dry matter production, as well as improved overall plant growth. According to Silva *et al*. (2011), nano-TiO_2 treated seed generated plants with higher dry weight, photosynthetic rate and chlorophyll-a production than the control, indicating that nanofertilizers considerably improve seed germination and overall plant growth. Benzon *et al*. (2015) investigated that except for the treatment that used solely nanofertilizer, all combination treatments considerably improved agronomic parameters. Plant height, chlorophyll content, quantity of reproductive tillers, panicles and spikelet all improved when the full recommended rate of conventional and nanofertilizer (FRR-CF+FRR-NF) was used. The increases were 3.6 per cent, 2.72 per cent, 9.10 percent, 9.10 per cent and 15.42 per cent over the FRR-CF, respectively. Panicle weight (17.4%), total grain weight (unpolished 17.5 per cent, polished 20.7 per cent), total shoot dry weight (15.3 per cent) and harvest index (2.9%) all showed similar findings. Rice growth, development, TPC and antioxidant activity were all boosted by nanofertilizer application, suggesting the potential to improve crop productivity and plant nutrition.

Directing the issues relating to the environmental degradation due to the- conventional fertilization

Use of nanofertilizers, maintaining crop yields and lesser greenhouse gas emissions are just a few of the technologies which proponents believe can boost agricultural yields while lowering agriculture's environmental impact (Lei *et al.,* 2007). Nanofertilizers can control nutrient release and give the exact amount of nutrients to crops in the right proportions, boosting productivity while assuring environmental safety (DeRosa *et al.,* 2010). Under nutritional limitation, crops exude carbonaceous chemicals into the rhizosphere, which can be used as environmental signals for the development of new nanofertilizers (Sultan *et al.,* 2009). The application of novel nanofertilizers has an advantage over traditional fertilizer application methods in that it releases nutrients in a regulated manner, preventing polluting of water resources (Sekhon,2014; Naderi and Abedi, 2012). The use of nanofertilizers increases element usage efficiency, minimizes toxicity caused by over application in the soil thus preventing pollution due to the use of fertilizers (Naderi and Danesh-Shahraki 2013).

Control of diseases

IFFCO nanonitrogen (nano N), IFFCO nanocopper (nano Cu), IFFCO nanozinc (nano Zn) and IFFCO sagarika were sprayed on the maize crop in various combinations with the recommended fertilizer doses. The treatment which had the application of 50 per cent N, 100 per cent PK, 0 per cent Zinc + 2 sprays of IFFCO nano N (4 ml/l) mixed with IFFCO Sagarika (2 ml) had the greatest influence on growth and yield metrics, with a maximum yield of 58.90 q/ha and the highest B:C of 2.99. Treatment which had the application of 50 per cent N, 100 per cent PK, 0 per cent Zinc + 2 sprays of IFFCO nano N (4 ml/l) mixed with nano Zn (2 ml/l) and IFFCO nano Cu (2 ml/l) was found to be superior in terms of Turcicum leaf blight disease management (Ajithkumar *et al*., 2021).

Methods of application of nano fertilizers

Soil application

Most frequent technique of nutrient supplementation using chemical and organic fertilizers is soil application. Fig 2 depicts the release of the nutrient from nano fertilizer in the soil. 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).

Methods of synthesizing the nano fertilizers

Nano fertilizers can be synthesized by physical (top-down), chemical and biological approaches. Physical approach is based on reducing the larger particles into smaller size. Examples of this approach are pearl/ball milling, nano morph technology, high pressure homogenization, microfluidizer technology (Yadav *et al.*, 2012; Kumar *et al.,* 2013). In the chemical method which is also called as bottom-up approach, starting with molecules in solution association of molecules to form nano particles is done using chemical reactions. Examples of this technique are precipitation method, hydrosol methods, spray freezing into liquid, or superficial fluid technology. Other methods for manufacturing the nano fertilizers are ionic gelation, complex coacervation, coprecipitation, solvent diffusion and self-assembly (Kumar *et al.*, 2012). The advantage of chemical synthesis above the physical synthesis is that the impurities can be reduced and particle size can be controlled (Singh and Ratanpal, 2014; Pradhan and Mailapalli, 2017). Biologically the nano particles can be made by using plants, bacteria, fungi and yeast. Fig 3 summarizes the methods of synthesizing of nano fertilizers, their advantages (green color text) and disadvantages (Red color text).

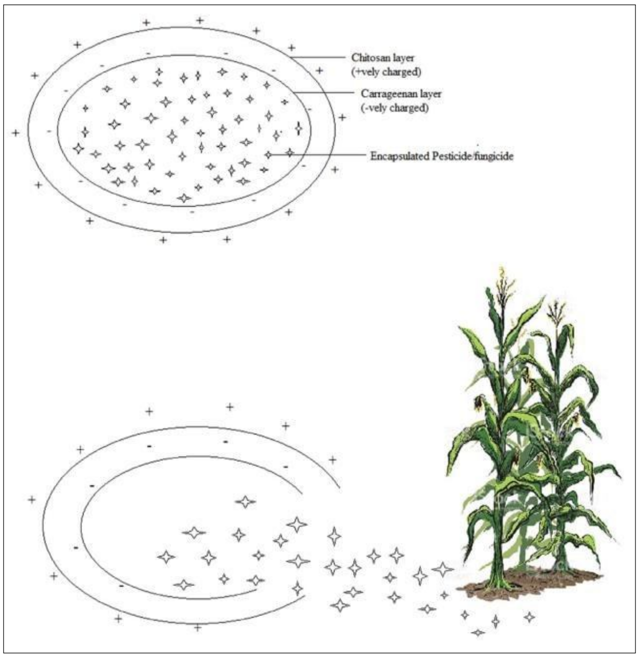


Fig 2: A schematic diagram of release of nutrients from the nano fertilizers. Source: Duhan *et al.* (2017).

Types of nanofertilizers

Nitrogenous nanofertilizers

Among the nitrogenous fertilizers, the most commonly used fertilizer used in India is urea. Researchers have concentrated their research on the usage of urea as the principal fertilizer, as the losses of nitrogen due to premature decomposition of urea before its uptake are very high (Kottegada *et al.,* 2017). To address the limitations of conventional fertilizers, nanotechnology and nanomaterials are being used to create more effective and efficient urea fertilizer. According to the findings, urea produced from nanohybrids with a 1:6 hydroxyapatite to urea ratio released urea 12 times more slowly than pure urea. Furthermore, the nanohybrid contained almost the same amount of accessible nitrogen as pure urea (Nair *et al.*, 2010). $NH4^+$ occupying the interior channels of zeolite can be released slowly and freely, allowing for gradual absorption by the crop and hence enhanced dry matter production (Millán *et al.*,2008). Urea-impregnated zeolite might be utilized as a slow-release fertilizer, releasing nitrogen slowly and steadily from nanozeolite. (Dwairi, 1998). The nutrient release pattern of nano fertilizer formulations delivering fertiliser nitrogen was studied by Subramanian and Rahale (2009). The results revealed that nanoclay-based fertilizer formulations (zeolite and montmorillonite with a dimension of 30-40 nm) can release nutrients for up to 1000 hours longer than traditional fertilizers (500 hours).

Phosphatic nanofertilizers

Encapsulation of the potassium dihydrogen phosphate with zeolite is done for release of the phosphorous and the percolation reactor is used. As the phosphorus use efficiency is 18-20% (Subarmanian *et al.,* 2015), it is very essential

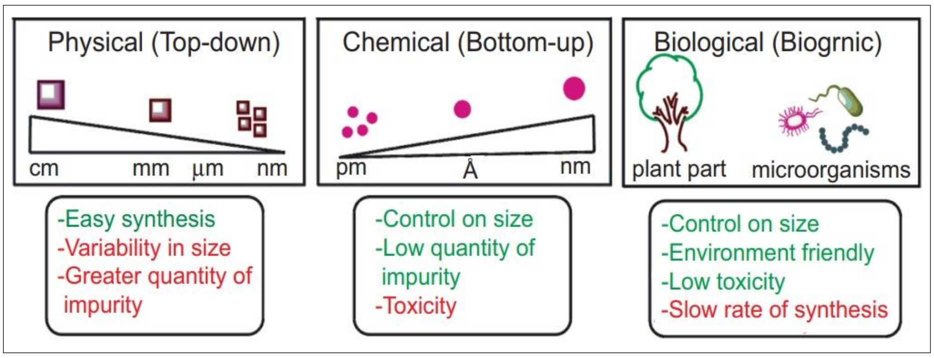


Fig 3: Methods for making nanofertilizers are depicted in this diagram. Source: Bernela *et al.* (2021).

that the phosphatic fertilizer use efficiency should be increased with the use of nano technology in agriculture. The use of nano and chemical phosphatic fertilizers greatly enhanced the nutritional content and uptake by the pearl millet crop in a pot culture trial. With the delivery of 2.5 times less RDP using nano phosphatic fertilizer, the greatest NPK content and uptake, as well as protein content and uptake, were observed (Dhansil *et al*., 2018).

Potassic nanofertilizers

Li and Zhang studied the hot pepper growth parameter and potassium dynamics in soil using potassium encapsulated with zeolite as a controlled release fertilizer. Plants exposed to 2/1000 Nano calcium chelate fertilizer and various amounts of Nano potassium chelate fertilizer demonstrated improved performance as compared to controls. The treatments with the highest One thousand seed weight ($P = 0.05$) were those with 2/1000 Nano calcium and 6/1000 Nano potassium concentrations (Ghahremani *et al*., 2014).

Zinc based nano fertilizers

The most widespread micronutrient deficiency in Indian soils is zinc. Zinc deficiency in Indian soils is anticipated to rise from 49 to 63 per cent by 2025, as most marginal soils brought under agriculture have zinc deficiency (Singh, 2006). Families consuming zinc-deficient crop produce had lower zinc levels in their blood plasma than consuming a diet produced from zinc-fertilized farms on a regular basis. Zinc supplementation is required to maintain high zinc levels in soil, seed and human and animal blood plasma (Singh *et al*., 2009). Nanofertilizers can be used for correcting the deficiency of zinc in Indian soils. For the species of Buck wheat (*Fagopyrum esculentum*), the effect of ZnO on root germination was observed (Sooyeon *et al*., 2013). Onion (Allium cepa) root elongation, genetic makeup and metabolism were all affected by ZnO nanoparticles. Corn root growth was inhibited after seed soaking and incubation in a suspension of Zn/ZnO nanoparticles. The toxicity of ZnO nanoparticles and Zn^{2+} could be caused by a variety of factors, including chemical toxicity based on chemical composition or stress or stimulation imposed by the size, shape and surface of the ZnO nanoparticles. Both ideas had an impact on the plants' cell culture responses. Internal efficiency, *i.e*., Zn/ZnO utilisation in tissues, or external efficiency, *i.e*., Zn/Zn absorption, may be the most important mode of action depending on the plant species and experimental settings (Dwivedi and Randhawa 1974). Hydroponically produced soybean plants absorbed ZnO NPs in the Zn^{2+} oxidation state. Later, it was proposed that ZnO NPs at the root surface changed their oxidation state to Zn^{2+} (LopezMoreno *et al*., 2010a).

Limitation of nanofertilizers

Despite the many advantages that nanotechnology has brought to fertilizer production, there are still limitations and drawbacks to be aware of. The main limitations are production availability and practical concerns, when it comes to large-scale applications. Furthermore, the greater production costs and lack of standardization can be regarded as substantial drawbacks (Iqbal, 2019). The risk of nanoparticles is higher because this technology is new to the world. There are a few researches done on its use in crops (Solanki *et al*., 2015).

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.

Conflict of interest: None.

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