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Review Article

NUTRIENT TRANSFORMATION THROUGH NANOFERTILIZERS IN SOIL

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Abstract *Global population growth during the past ten years has compelled the agricultural industry to boost crop yield to meet the requirements of billions of emerging nations. Widespread nutrient shortage in soil has caused a major nutritional value decline and substantial financial losses for farmers. Agriculture can only grow by using modern innovations wisely to raise output. The application of nanotechnology to plant science and agriculture has increased recently. The development of nanotechnology has made it easier to produce physiologically significant metal nanoparticles on a large scale. These nanoparticles are currently utilized to enhance fertilizers formulation for greater plant cell absorption and reducing nutrient loss. Ongoing study provides a fresh impression of nanoparticles (NPs) biosynthesis, their use as nano-fertilizers and nano-pesticides, their application in agriculture, and their contribution to improving the performance of bio factors. An overview of NPs-plant interactions, the destiny and fate of nanomaterials in plants, and the role of NPs in reducing the negative impacts of toxicity and stress has been provided. The information in the current review paper is essential for identifying the restrictions and potential uses of nano-fertilizers as a replacement for traditional fertilizers in the future.*

Keywords: Modern technologies; Nano-fertilizers; Nano-particles; Ecofriendly; Synthesis

Introduction

The agricultural sector is confronted with several global hitches, comprising urbanization, climate change, resource sustainability, and environmental issues such as the accumulation of fertilizers, run-off, and leaching. Decreased crop production, reduced organic matter, low nutrient use efficiency, climate change, nutrient deficiency, and labor shortage with emigration of people from farming speed up these issues. Fertilizers account for 35-40% of agricultural productivity, however, some fertilizers have a direct effect on plant growth. Nanotechnology can be a source for overcoming these problems through a more accessible approach. Because fertilizers are a significant concern, producing nano-based fertilizers would be a novel technology (Nagula and Usha, 2016). Nanotechnology has a significant role in agriculture as it provides different nano-materials and nano-devices such as nano fertilizers effectively manage nutrients, nanoparticles increase seed vitality, nano-pesticides and nano-herbicides are used for pest management and weed control respectively, nano-sensors determine the soil nutrient status and moisture content. They are used for nutrient and water management. Alginate/ chitosan nano-herbicides can act as herbicide carriers (Singh, 2017).

Fertilizers are vital features of agricultural production systems for maintaining soil health. It was essential in increasing the yield of various crops, particularly food grains (Subramanian and Thirunavukkarasu, 2017). Although chemical fertilizers application reliably expands the soil nutrient status and yield production with few related effects such as low nutrient use efficiency, imbalanced fertilization, and multi-nutrient deficiency have driven the presentation of nano-fertilizer technology (Subramanian and

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Thirunavukkarasu, 2017). Current world agricultural cropping frameworks intend to use many herbicides, insecticides, and fertilizers to achieve greater production per unit area, however, using further measures than optimal of these fertilizers causes a few drawbacks (Subramanian and Tarafdar, 2011).

Nano-fertilizers may be feasible agricultural adaptations for much better insect and nutrient administration. These nanomaterials have more entry capacity, surface area to volume ratio, and usage proficiency that keeps a strategic distance from deposition in the environment. Nano-particle with diameters around 100 nm is used as fertilizer for nutrient administration, reducing pollution and being more eco-friendly (Singh, 2017).

Applying different nano-fertilizers improves crop yield, reducing the fertilizer rate for crop generation and lowering the danger of contamination. Using nano-fertilizers can improve fertilizer supplements' effectiveness in crop production. Nano fertilizers promote growth and optimum crop yield but also diminish crop development and production. If value added is higher than ideal, it results in decreased crop development and yield (Singh, 2017). Using nano fertilizer in the soil increases component production, reduces soil toxicity, and reduces fertilizer use. Nano fertilizers facilitate nutrient release as needed and prevent them from abruptly transforming into gaseous forms that plants cannot take up (Naderi and Danesh-Shahraki, 2013; Nagula and Usha, 2016). For this purpose, a biosensor may be fitted to this nano fertilizer, allowing for customized N-emission based on time and soil nutrient conditions. Controlled or slow-release fertilizer flow may reduce the harmful effects of fertilizer over-application and improve the soil (Subramanian and Thirunavukkarasu, 2017). Nano fertilizer development is incredibly imaginative, although less specific literature is available in scholarly journals. Several publications and protected items suggest a huge space for nano fertilizers (Subramanian and Thirunavukkarasu, 2017).

Nano fertilizers can potentially reduce nitrogen loss owing to volatilization, leaching, and soil microorganism consolidation for the long-term, which significantly impact the environment (Butt and Naseer, 2020; DeRosa et al., 2010). Nano coatings and innovation can help reduce expenses and increase farm efficiency in various ways, i.e., improvement in moisture retention, carbon sequestration, and soil aggregation. Furthermore, output per hectare basis is substantially more than with conventional fertilizers, providing farmers with more significant profits. Nano fertilizers and nanoparticles can manage nutrients released from fertilizer, advancing nutrient utilization efficiency while preventing nutrient particles from becoming settled or lost in the environment (Preetha and Balakrishnan, 2017; Subramanian et al., 2008). Nano fertilizers use promotes nutrient efficiency, which lowers the expense of natural contamination (Chinnamuthu and Boopathi, 2009). Nano fertilizers are supposed to be a viable option for meeting the plant's nutrient requirement, and crop yield. The fertilizers coated with nanoparticles release nutrients slowly that plants can quickly uptake (Butt and Naseer, 2020). Nanostructured fertilizers can improve essential nutrient usage efficiency by utilizing tools such as targeted administration, moderate or controlled discharge. They may completely discharge their dynamic fixes in response to natural stimuli and needs. Later, different lab research revealed that nano fertilizers could enhance yield production by increasing seedling growth, seed germination, photosynthesis activity, and carbohydrate and protein mix efficiency. However, as a new technology, the ethical and safety concerns surrounding nanoparticle application to plant are limitless and should be appropriately studied before its use in agriculture (Solanki et al., 2015).

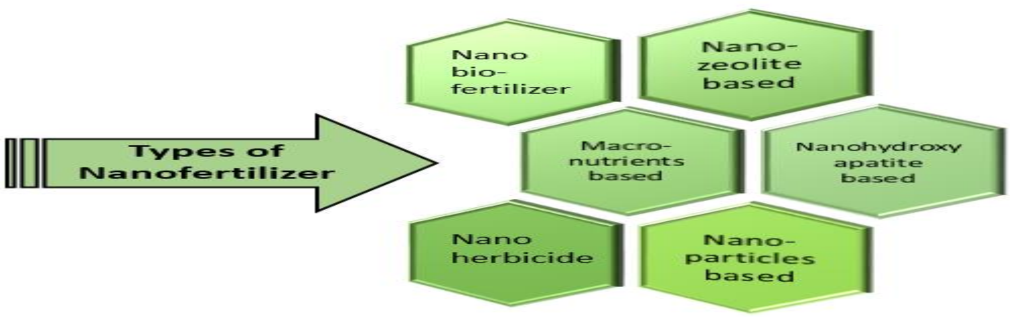

Fig.1. Types of nano fertilizer

Nano fertilizer and its preparation

"Nano" is a Greek origin word meaning dwarf and is the billionth part of a meter. Some nanoparticles have a diameter of less than 100 nm (Thakkar et al., 2010). They possess a nanoscale, larger surface area, and unique qualities that make them extremely useful (Solanki et al., 2015). Lately, many scientists developed nanomaterials that would offer all essential nutrients in a precise dosage with an ingenious delivery mechanism. Nanotechnology has

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the potential to provide customized fertilization. Nanoparticles can be used as fertilizer and administered as a foliar spray to boost yield. It was discovered that foliar applying nano phosphorous to pearl millet and bean at 640 mg ha^{-1} in a dry environment improved productivity**.** The physicochemical characteristics of nanomaterials are different from the bulk material. Using nanoparticles prepared from rock phosphate on crops may inhibit the fixation of nutrients in the soil. Lack of iron, calcium, and silicic acid that fix phosphorus may improve phosphorus availability to crop plants. Nano fertilizers encapsulation can be done in three different ways i.e., by a thin defensive coating of polymer, by nanomaterials such as nanoporous materials or nanotubes or is delivered as nanoscale emulsions or particles. Different types of nano-fertilizers have been introduced recently (Fig. 1). Nano-fertilizers provide crop nutrients through nanoparticles (Subramanian and Thirunavukkarasu, 2017). They slowly release the nutrients in response to various signals, including warmth, wetness, and other abiotic stress. They have the potential to manage the controlled release of nutrients, adequate supply of nutrients to crops, improve crop yield, and maintain environmental safety (DeRosa et al., 2010; Kumar et al., 2021).

Nano fertilizers are modified versions of traditional chemical fertilizers by various physical, biological, and chemical tactics with the help of nano-based interventions. Nano fertilizers have unique qualities that distinguish them from bulk materials. They also offer significant benefits over fertilizer (as described in Table 1) and are generally used to increase crop yield and soil nutrient status (Brunner et al. 2006).

Table 1. Comparison of nano fertilizers with conventional fertilizers

Properties	Nano-fertilizers	Conventional fertilizers
Solubility	High	Low
Adsorption capacity	Lesser	Higher
Bioavailability	High	Low
Nutrient uptake efficiency	High	Low
Nutrients release	Slow and controlled	Rapid
Loss rate	Less	High
Effective duration of nutrient release	Increase the distribution into soil	At the time of application only

Different studies showed that applying nano fertilizers enhanced yield production over no nano fertilizers. This is primarily due to higher plant growth and photosynthesis, which leads to high photosynthates accumulation and movement to economically important plant parts. Foliar spray of nano fertilizers considerably improves crop production (Singh, 2017). Nano fertilizers diffuse with nutrients, particularly NO_3-N, for over 50 days, whereas the release of nutrients from synthetic fertilizers ceases after 10-12 days, however, nano fertilizers release nutrients slowly on crop requirement (Subramanian and Rahale, 2012; Subramanian and Thirunavukkarasu, 2017). As a result, the properties of nano fertilizers include: 1. Nutrient carriers along with Nano dimensions having a range 30-40 nm with higher surface area storing nutrients and using other features of nanoparticles (Subramanian et al., 2015). 2. Nano fertilizers increase the nutrient status within soil without any side effects because they release the nutrients slowly for more than 30 days; 3. These nano fertilizers can be manufactured by supplementing nutrients alone or in combinations on nanoparticle surface that distribute nutrients slowly for longer, where significantly reduced nutrient loss enhances environmental safety (Belal and El-Ramady, 2016; Subramanian et al., 2015).

Preparation of Nano fertilizer

Nutrient loading on nanoparticles is often accomplished by absorption and Ligand-mediated attachment of nutrients on nanoparticles, coating with polymeric shell, trapping of polymeric nanomaterials, and synthesis of nutrient-containing nanomaterials. Nanoparticles can be prepared differently for nano fertilizers, as shown in fig. 2, including top-down, bottom-up, and biological techniques (Nagula and Usha, 2016). The top-down strategy is often used less than the bottom-up approach. Top-down approaches include volatilization, condensation, milling, and chemical techniques (Ghorbani, 2014).

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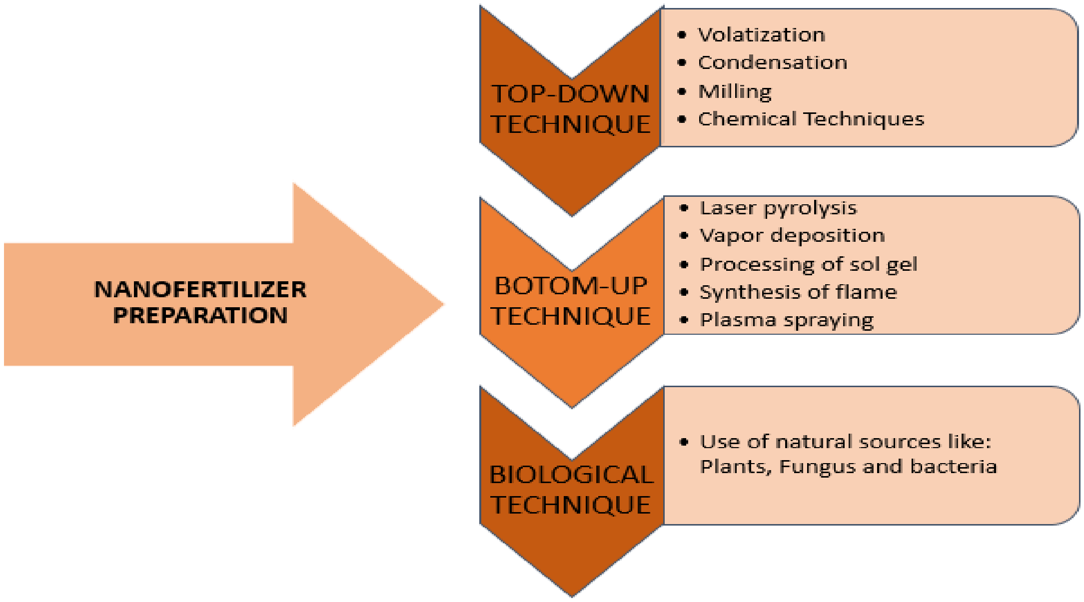

Fig.2. Preparation of nano fertilizer

The downside of this strategy is that there is less control for nanoparticles size and a higher number of impurities (Zulfiqar et al., 2019). Different materials are built from molecular components in the bottom-up method. Laser pyrolysis, vapor deposition, condensation, sol gel processing, and flame or plasma spraying synthesis are among the processes used (Nagula and Usha, 2016). Along with the physicochemical techniques, nanoparticles can be prepared biologically using a technique known as biosynthesis. Various natural sources for this function include plants, fungi, and bacteria. The advantage of this method is that it allows for more control over particle size and toxicity (El-Ramady et al., 2018; Yadav et al., 2012; Zulfiqar et al., 2019).

Uptake and fate of Nano fertilizer

Nano fertilizers increase the effectiveness of elements in soil and reduce toxicity and the number of fertilizers applied to reduce the negative impact of excessive fertilizers intake (Naderi and Danesh-Shahraki, 2013; Nagula and Usha, 2016). All the processes associated with nano fertilizers involving uptake, translocation, and accumulation are affected by different factors such as environment, plant species, age, and physicochemical characteristics of nanoparticles stability, functionalization, and delivery mechanisms of nanoparticles (Solanki et al., 2015). The nutrients are delivered to the plants slowly by dissolution and ionic exchange in a demand-driven manner. Nutrient adsorption promotes these processes, which pulls the nutrients away as needed. Zhou and Huang (2007) reported that nano-zeolite releases K slowly and steadily because zeolite can exchange specific nutrients. It can be an effective medium for plant development as it provides necessary nutrient cations and anions to plant roots (Nagula and Usha, 2016). Concentrations of different nanoparticles beneficial in plants are shown in Table 2.

Nano porous Zeolite slows the delivery of fertilizers to the plant, allowing the plant to absorb the full quantity of nutrients from the fertilizers delivered rather than just a small amount. Because of the large surface area of nano fertilizers, more nutrients can be adsorbed within and taken up by plants when needed (Naderi and Danesh-Shahraki, 2013). It may be loaded with nutrients i.e., nitrogen, potassium, integrated phosphorus, calcium that dissolves slowly, and a full suite of trace nutrients (Nagula and Usha, 2016). Nanoparticles can enter plants by making complexes with cell membrane transporters or root exudates (Kurepa et al., 2010). Some investigations have found that movement of nanoparticles in the leaf can occur through stomata or by trichrome base (Arshad et al., 2016; Eichert et al., 2008; Fernández and Eichert, 2009; Solanki et al., 2015). Nanoparticles can move apoplastically and symplastically once within the cell. Plasmodesmata may transmit them from cell to cell (Rico et al., 2011). Nanoparticles approach many organelles in the cytoplasm and interact with various cells' metabolic processes (Solanki et al., 2015).

If the particle size of NPs is smaller than the diameter of cell wall pores, they enter plant cells straight by sieve- like structures of the cell walls (5 to 20). However, the subsequent passage of nanoparticles through the membrane, their interactions with the cytoplasm, and the use of NPs transporting nutrients are too complex and are beyond the scope of this study, partially due to a minimum number of relevant research (Liu and Lal, 2015).

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Table 2. Beneficiary concentrations of different nanoparticles in plants

Nanoparticles	Plants	Concentration	References
ZnO-NPs	Chickpea	1.5 mg/L	Farhana et al., 2022
	Cucumber	400 mg/L	Ghani et al., 2022
	Mung bean	20 mg/L	Mazhar et al., 2023
Se-NPs	Tobacco	50 mg/L	Bano et al., 2021
	Wild Radish	100 mg/L	Cheng et al., 2022
SiO-NPs	Maize	7.5 mg/L	Ghoto et al., 2020
FeO-NPs	Mung bean	50 mg/L	Sun et al., 2020
CuO-NPs	Wheat	50 mg/L	Badawy et al., 2021

The absorption and translocation of Cu nanoparticles in wheat and mungbean were studied in agar culture media. It was discovered that Cu nanoparticles may pass the plant cell membrane and clump together inside the cell (Lee et al., 2008) . Like the definitive research on TiO2 and ZnO NPs, most investigations on plant absorption, translocation, and accumulation are only reported until the germination stage. As a result, the fate and transportation of nanoparticles in plants is mostly unclear (Rico et al., 2011; Solanki et al., 2015). Readers interested in preliminary investigations on NP interactions with plants are directed to relevant reviews (Lin et al., 2010; Liu and Lal, 2015; Ma et al., 2010; Nair et al., 2010).

Macronutrient Nano fertilizer

Macronutrient usage in agriculture is expected to rise by 265 million tons by 2020 (Wang et al., 2016; Zulfiqar et al., 2019). Nitrogen and phosphorus are critical in crop production, environmental protection, and food security compared to other nutrients. As a result, the development and use of nano fertilizer with maximum effectiveness (reduced leaching and gasification rate, less soil immobilization rate, and higher uptake rates by plants), low security, and environmental risks (low Nitrogen leaching to groundwater and less potential for eutrophication) are critical and higher research priority for the time being (Liu and Lal, 2015). Macronutrients, including the primary and secondary macronutrients such as nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), and Sulphur (S), have been mixed with nanomaterials to supply a precise quantity of nutrients to crops while minimizing bulk needs and lowering purchase and shipping costs. These nano fertilizers of macronutrients are made up of one or more than one nutrient that has been encapsulated in a particular nanomaterial.

Nitrogen nano fertilizer

Nitrogen is an essential constituent of all plant cells that is required by genetic, metabolic, structural, and photosynthetic molecules (Basavegowda & Baek, 2021). It is accessible to plants in three forms: organic, nitrate (NO_3^-), and ammonium ions (NH_4^+). Most of the nitrogen is not accessible to plants because NO3- does not sorb on the surface of negatively charged soil particles with a lower affinity (Preetha and Balakrishnan, 2017).

Slow-release fertilizers such as zeolite, halloysite, bentonite, and montmorillonite have been produced using bio or synthetic polymers because of their leaching, high solubility, and denitrification. Many techniques, including urea coated with polyolefin, sulfur, and neem, have been employed to limit N release and prevent leaching throughout fertilization. Compared to standard bulk fertilizers, nanohybrid fertilizers i.e., urea hydroxyapatite, release N evenly and improve the growth and development of plants (Basavegowda and Baek, 2021; Kottegoda et al., 2011). Another nanoparticle, clinoptilolite zeolite (CZ), having a porous nature, higher cation exchange capacity (CEC, up to 300 $cmol_c$ Kg^{-1}), and high affinity for NH_4^+ is used for lowering NH_3 emissions from the farm manure and for reducing or remove its toxicity to plants (Gupta et al., 1997). CZ-retained ammonium is often subjected to delayed release in soil via cation exchange capacity and nitrification (Kithome et al., 1998; Preetha and Balakrishnan, 2017). Due to the lower cost per unit, urea has been the nitrogen source that is utilized mostly. However, urea's N utilization efficiency may be lowered due to its loss from the agricultural system caused by ammonia volatilization to atmosphere. This is a primary reason for urea's poor efficiency, and it can reach high levels, approaching 80 percent of the nitrogen applied (Preetha and Balakrishnan, 2017). Many slow-release/controlled nano fertilizers with promising results have been investigated as a nitrogen source e.g., hydroxyapatite, zeolite (urea modified), and mesoporous silica nanoparticles.

Practices are made to enhance NUE (Nutrient use efficiency) using nanotechnology by entrapping nitrogen in matrix of clay or intercalation technique. Zeolite, a natural mineral, has large surface area with sieving capability, making it a unique substrate for producing nano fertilizers. The NUE from NFs was 82 percent whereas the conventional fertilizer recorded 42 percent, with net higher NUE of 40 percent, which is difficult to achieve in conventional systems (Subramanian and Rahale, 2012). All these studies showed that the nano-fertilizers can gradually control the delivery of nutrients over time. In many situations, there was an initial release followed by a

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gradual and constant release over a longer period, which might not have corresponded to crop development. Nano technology can aid in developing a personalized nano fertilizer that may release nutrients in line with crop nutritional requirements, which can be accomplished by detecting the biochemical signals generated from root exudates (DeRosa et al., 2010). It shows that NFs might be used for smart nutrient delivery in agriculture (Subramanian and Thirunavukkarasu, 2017).

Phosphorus nano fertilizer

Phosphorus plays its role as an essential macronutrient since it is a part of several major plant structural compounds and a catalyst component in multiple plant biochemical processes. Phosphorus is the most critical nutrient due to its role in plant energy transport and storage (Preetha and Balakrishnan, 2017). The availability of phosphorus in soil is a mystery since it is fixed throughout a wide pH range. Furthermore, less than 1% phosphorus is in an accessible form that plants can use readily, while the remainder is unavailable. P slowly moves in soil solution, and phosphates form precipitation with the counteracting cations Fe, Zn, Ca, and Mg. To avoid and overcome such precipitation processes, phosphate ions are encapsulated in a nano matrix (Subramanian and Thirunavukkarasu, 2017). Furthermore, soluble phosphorus fertilizer, such as SSP or TSP, damages the water reserves, resulting in eutrophication and extinction of water bodies. Because excessively soluble fertilizers have a detrimental environmental impact, the nano P fertilizers with reduced solubility and mobility have a more beneficial influence on crop growth and development (Basavegowda and Baek, 2021). A nano-based suspension of water and phosphorite having particle size 60-120 nm was developed as a bio-safe P nano fertilizer. This phosphatic NF was created from deposits of Tatarstan's Syundyukoyskoe taken as raw phosphorite by ultrasonic material dispersion. This experiment showed that investigated plant species' production, quality, and quantity rose many folds (Patra et al., 2016; Zulfiqar et al., 2019).

Zeoponic delivers nutrients to plants when needed i.e., in a demand-driven way that uses controlled dissolution of synthetic apatite to release phosphate (PO_4^{3-}) and other minerals. Zeoponics delivered NPK when the plant needed them (Preetha and Balakrishnan, 2017). The procedure is essentially a mix of dissolution and ionic exchange processes. Plant roots absorb nutrients from the soil solution, which causes the dissolution and ionic exchange processes that draw nutrients away as needed. More dissolved nutrients are added to the zeolite to "recharge" it. By generating a nourishable and balanced supply of nutrients in the plant root zone, zeoponics promote soil retention of nutrients, reduce the environmental losses of nutrients and reduce requirements of fertilizers (Preetha and Balakrishnan, 2017). Rop et al., (2018) suggested that nano-hydroxyapatite and soluble phosphorus fertilizers minimized leaching and nutrients toxicity in root zone when added to water hyacinth cellulose-graft-poly (acrylamide) polymer hydrogel. Compared to normal P fertilizer [$Ca(H_2PO_4)_2$], similar findings from synthetic hydroxyapatite [$Ca_5(PO_4)_3OH$] NF demonstrated enhanced growth and seed yield in soybean (Basavegowda and Baek, 2021; Liu and Lal, 2014).

Surface Modified Zeolite (SMZ) is an excellent sorbent, and delayed P release is possible. Maize was grown for 30 days in a culture medium for solution (Subramanian and Thirunavukkarasu, 2017). It was then treated with various P nanoparticles. Maximum growth rates in terms of shoot and root length, volume, uptake, P concentration, and dry matter yield were found with hydroxyapatite (200nm) followed by $CaPO_4$ (100nm) and Rock phosphate (42 nm), respectively (Subramanian and Thirunavukkarasu, 2017). PO_4 - release pattern of surfaces treated with different zeolite and nano clay in a filtration reactor. Results showed that nano-formulations released phosphate over 40-50 days, whereas conventional fertilizers' nutrients were released only in 10-12 days (Rahale, 2011). According to the literature reviewed, SMZ might be a promising technique for increasing P usage efficiency, which in conventional systems merely exceeds 18-20% (Preetha and Balakrishnan, 2017).

Potassium nano fertilizer

Potassium (K) is required for protein synthesis, translocation of photosynthates, plant stomatal regulation, photosynthesis, ionic balance, water consumption, enzyme activation, and various other functions. According to a recent study, spraying Lithovit coupled with potassium nano fertilizer on leaves increased sweet pepper plants' quality, quantity and development (Abd El-All, 2019; Basavegowda and Baek, 2021). Potassium-zeolite releases potassium slowly (del Pino et al., 1995; Zhou and Huang, 2007). Nano-zeolite releases potassium slowly and steadily (Zhou and Huang, 2007). This might be owing to zeolites ion exchangeability with specific nutrient cations. K-zeolite may be an ideal growth medium for plants to supply roots with more critical nutrient ions (Subramanian and Thirunavukkarasu, 2017). Some natural zeolites contain higher exchangeable K^+ levels, which help plants thrive in pot soils. Hershey et al. (1980) gave information on delayed release of potassium from potassium zeolite. Rahale (2011) investigated the efficiency of delayed release K fertilizers. Irrespective of dynamic equilibrium and K fixation in soil support soil K availability, nanotechnology can increase nutrients'-controlled

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release and availability (Preetha and Balakrishnan, 2017).

Secondary nutrients nano fertilizer

Secondary macronutrients such as sulphur (S), magnesium (Mg), and calcium (Ca) are required in relatively significant levels for optimum crop yield production (Preetha and Balakrishnan, 2017). Sulphur is necessary for chlorophyll formation and using P and other important minerals. According to Salem et al., Sulphur NPs may prevent a variety of crop diseases as well as the development and production of Cucurbita pepo. Compared to CF, the Ca nano fertilizers produced biosynthetically boosted biomass of shoots and nutritional content in the peanut plant roots (Basavegowda and Baek, 2021; Xiumei et al., 2005).

Zeolite is a slow/controlled fertilizer for Ca and Mg (Supapron et al., 2002). They proposed zeolite-enhanced soil Ca and Mg levels. They proposed that zeolite increased soil calcium and magnesium levels. Zeolite may readily exchange nutritional ions such as calcium and magnesium (Fansuri et al., 2008; Preetha and Balakrishnan, 2017). These macronutrient NFs lowered soil associated environmental concerns and irrigation water usage, retaining normal growth and yield, making them extremely beneficial for use (Basavegowda and Baek, 2021).

Micronutrient Nano fertilizers

Substances needed by plants in low concentration are termed micronutrients yet are critical to maintaining crucial metabolic processes in plants (Sharonova et al., 2015). Fe, Zn, B, Cu, Cl, Mn, and Mo are important that crops require in lesser levels than macronutrients like N, P, and K. They play key roles in activities like synthesis of glucose and proteins, nutrient control, reproductive growth, auxin regulation, chlorophyll production, fruit and seed growth and development, and defend dangerous plant diseases (Basavegowda and Baek, 2021; Tripathi et al., 2015).

Many Asian nations are deficient in micronutrients owing to calcareous soils, poor SOM, persistent drought, irrigation water with high bicarbonate concentration, and uneven use of nutrient fertilizers. Some detrimental outcomes of stress in plants brought on by micronutrient shortage include decreased crop output, poor quality, inefficient morphological plant structure (as seen by fewer xylem vessels), extensive infection and insect infestations, and decreased fertilizer usage capacity (Butt and Naseer, 2020; Malakouti, 2008). To address the problems with traditional micronutrient fertilizers such as leaching (e.g., Mo) or soil fixation (e.g., Zn, Fe or Cu), micronutrient research should focus on boosting the bioavailability of these fertilizers. More importantly, research is required to contrast the advantages of these micronutrient nano fertilizers in the field with those of their commercially accessible micronutrient counterparts (Liu and Lal, 2015). Nano fertilizers have known functions in the soil for plant growth and development, as described in fig. 3.

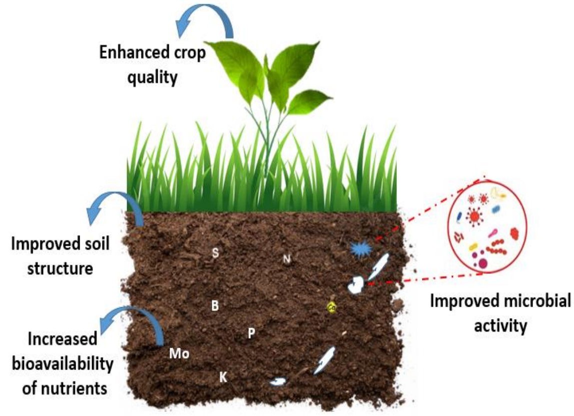

Fig.3. Functions of nano fertilizer

Zinc (Zn) nano fertilizer

Zinc is crucial for plant growth and development because it is a structural component or a regulatory cofactor for numerous enzymes and proteins (Noreen et al., 2018). Zn also plays a part in glucose synthesis, protein metabolism, auxin control, and plant defense against dangerous infections (Broadley et al., 2007; Zulfiqar et al., 2019). Since more than 95% of the added Zn is fixed, several strategies have been tried with different degrees of success to raise the Zn utilization efficiency of crops.

In recent years, nanotechnology innovations like "core shell"-fortified Zn boost rice's Zn nutrient status whether it is cultivated in aerobic or submerged circumstances (Yuvaraj and Subramanian, 2019). Schmidt and Szakál (2007) also tested the foliar application of ion-exchanged zeolite to winter wheat for a very long duration. The increase in crude protein caused by zinc zeolite treatment was observed to be better than copper. Zeolite in the soil can help plants retain and distribute nutrients (Eberl, 2002). It distributes small amounts of nutrients to zeolite exchange sites where they are more quickly available for plant absorption, which causes the gradual delivery of Zn. (Broos et al., 2007; Preetha and Balakrishnan, 2017).

Iron (Fe) nano fertilizer

Iron (Fe) is another important component that plants require in trace levels for appropriate growth and development. Despite being present in limited amounts, its absence or overuse compromises crucial plant physiological and metabolic processes, reducing yield (Palmqvist et al., 2017). As a result, using Fe to optimize yields in horticultural crops is crucial. The effects of iron oxide nanoparticles and ferric ions at various concentrations on citrus plants' physiological and morphological changes were investigated in this regard. Iron oxide nanoparticles

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were discovered in plant roots; however, they were not transported from root to shoot (Zulfiqar et al., 2019). Fe NFs can facilitate continuous and progressive Fe movement from roots to shoots, which is advantageous for soybean plants (Cieschi et al., 2019). In comparison to CFs, *Pisum sativum's* and *Glycine max* application of a Fe_2O_3 NF boosted the plant's chlorophyll content, shoot and root dry biomass (Basavegowda and Baek, 2021; Cieschi et al., 2019; Delfani et al., 2014). In a hydroponic greenhouse test, low doses of superparamagnetic Fe-NPs significantly increased the amount of chlorophyll in the sub-apical leaves of soybean. According to Ghafariyan, et al. (2013), this form of Fe-NP might be used by soybean as a source of Fe to reduce chlorotic symptoms of insufficient Fe (Liu and Lal, 2015). Sheta et al. (2003) investigated the ability of five natural zeolites and bentonite minerals to absorb and release zinc and iron. The sorption potential was computed using the Langmuir and Freundlich equations. According to the study, natural zeolites, particularly chabazite and bentonite minerals, offer a large potential for Zn and Fe sorption and an improved capability for slow-release fertilizers (Preetha and Balakrishnan, 2017).

Manganese (Mn) nano fertilizer

Manganese (Mn) is required for morphological and biochemical activities, and acts as a cofactor of enzymes, it also provides plants with the capability to endure environmental stresses. Mn is also vital for producing ATP, photosynthesis, chlorophyll, proteins, and the formation of secondary metabolites (Palmqvist et al., 2017; Zulfiqar et al., 2019). Mn fertilizers increase N metabolic activity (Pardha-Saradhi et al., 2014) ,boost the chickpea crop yield in semi-arid environments (Janmohammadi et al., 2015), and enhance peanut crop productivity along with yield attributes in sandy soils (Rui et al. 2016). By applying Mn NPs to the leaves, mungbean was enhanced, with longer roots and shoots, more rootlets, and more biomass (Pardha-Saradhi et al., 2014) and 'squash plant' growth along with output to the bulk Mn sulphate ($MnSO_4$) treatment was also improved (Belal & El-Ramady, 2016).

Copper (Cu) nano fertilizer

An incubation study of three-days with a kind of water-weed (Elodea densa planch) found that low applications of Cu NPs boosted plant photosynthetic rate by 35% in comparison with the control (with no copper) (Liu and Lal, 2015; Nekrasova et al., 2011). NPs, CuO, and ZnO dramatically increased growth and shoot dry weight in maize plants compared to the unprocessed reference (Adhikari et al., 2015; Basavegowda and Baek, 2021).

Boron (B) nano fertilizer

Boron is engaged in plant cell wall lignification, development, and further physiological activities. Plants require boron, but excessive amounts can be toxic to living things. Many scientists have looked into the adsorption of boron by clays, soils, and other minerals in great depth (Bryjak et al., 2008; Preetha and Balakrishnan, 2017; Sabarudin et al., 2005).

Molybdenum (Mo) nano fertilizer

Legume crops require molybdenum because they depend on plant enzymes like nitrate reductase and the nitrogen-fixing bacterial enzyme nitrogenase. The Mo fertilizers promote the maturation of Chama crista rotund folia by improving the cell wall and membrane integrity (Basavegowda and Baek, 2021; Weng et al., 2009). Consequently, the data indicate that nano-fertilizers supply nutrients for more days than regular fertilizers. This is incredibly significant in tropical agriculture, where moisture availability is uncertain, and fertilizer control release is optimal. Although nutrient discharge is moderate and permanent, multiple studies have shown a burst of nutrients right after implementation, accompanied by a steady and regular release. More research is intended to supply customizable fertilizers that provide nutrients according to crop demand. Scientists involved in nano fertilizers study will have difficulty providing nutrients to crops. Additionally, the biosafety of nano fertilizers must be undertaken in alignment with the Organization for Economic Cooperation and Development (OECD) rules to ensure environmental protection (Subramanian and Thirunavukkarasu, 2017).

Conclusion

Overusing fertilizers to increase agricultural yield has unintended environmental and ecological consequences, such as altered soil fertility, compromised plant nutrition, and a weakened ecosystem. It's crucial to enhance agricultural productivity with little environmental impact. Advanced nano-biotechnological tools and approaches can help make sustainable agriculture in the approaching era of agricultural mechanization. A nanoparticle loaded with organic fertilizers is an ideal "nutrient booster" because it permits the progressive and continuous nutrient release to plants, achieving the proper nutrient supply during their growth period. Organic amendments should be combined with nano fertilizers wherever possible to enhance effective nutrient utilization and increase soil health. Nano slow-release fertilizers may provide several advantages for plants, including better functional component stability, micro dosages, reduced nutrient loss due to leaching and degradation, masked soil nutrient deficiencies, and enhanced crop output. Therefore, nano-based agricultural improvement has great potential and may be an inexpensive and ecologically benign solution for expanding sustainable agriculture.

Future perspective

With limited space and resources, increasing agricultural productivity and dietary security requires

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an environmentally friendly strategy, and this is where the cutting-edge perspective of biotechnology and nanotechnology for sustainable plant management originates. Nanotechnology provides a solution in the form of nano biofertilizers for sustainable agriculture management towards a promising future.

Improved functional component stability, reduced nutrient loss through leaching and degradation, concealed soil nutrient depletion, and enhanced crop production attributes are potential benefits of nano bio-slow-release fertilizer for plants. Because of their inherent low cost and little impact on the environment, nano fertilizers are often regarded as the wave of the future in environmentally responsible farming. However, the potential risks of using nanomaterials must be assessed before this technology can be appropriately applied in agriculture. Keeping in mind the positive and negative characteristics of nano fertilizers, it is crucial to make considerable efforts to promote cutting-edge research to appropriately compensate for the hazards associated with using nano materials.

- The viability of nano fertilizers in the agricultural industry cannot be entirely advanced by laboratory experiments alone. Any experiment designed to assess the effects of nanoparticles on the environment should be conducted in a natural setting for accurate results.
- Systematic and government-based security evaluations should be performed to confirm nanoparticle dosage's allowed and safety limit. More study and clear definitions based on actual natural field settings are needed to manage the negative impacts of using organic waste.
- Biodegradability and biomagnification transfer effects must be accounted to grasp the toxicity of micro fertilizer applications on plants completely.

References

Abd El-All, A. (2019). Nano-Fertilizer application to increase growth and yield of sweet pepper under potassium levels. *Agri. Res. Tech.: Open Access J*, **19**(4), 145-156.

Adhikari, T., Kundu, S., Biswas, A., Tarafdar, J., & Subba Rao, A. (2015). Characterization of zinc oxide nano particles and their effect on growth of maize (Zea mays L.) plant. *Journal of Plant Nutrition*, **38**(10), 1505-1515.

Arshad, M., Merlina, G., Uzu, G., Sobanska, S., Sarret, G., Dumat, C., . . . Kallerhoff, J. (2016). Phytoavailability of lead altered by two Pelargonium cultivars grown on contrasting lead-spiked soils. *Journal of soils and sediments*, **16**(2), 581-591.

Bano, I., Skalickova, S., Sajjad, H., Skladanka, J., & Horky, P. (2021). Uses of selenium nanoparticles in the plant production. *Agronomy*, **11**(11), 2229.

Basavegowda, N., & Baek, K.-H. (2021). Current and future perspectives on the use of nanofertilizers for sustainable agriculture: the case of phosphorus nanofertilizer. *3 Biotech*, **11**(7), 1-21.

Badawy, A. A., Abdelfattah, N. A., Salem, S. S., Awad, M. F., & Fouda, A. (2021). Efficacy assessment of biosynthesized copper oxide nanoparticles (CuO-NPs) on stored grain insects and their impacts on morphological and physiological traits of wheat (Triticum aestivum L.) plant. *Biology*, **10**(3), 233.

Belal, E.-S., & El-Ramady, H. (2016). Nanoparticles in water, soils and agriculture *Nanoscience in food and agriculture 2* (pp. 311-358): Springer.

Broadley, M. R., White, P. J., Hammond, J. P., Zelko, I., & Lux, A. (2007). Zinc in plants. *New phytologist*, **173**(4), 677-702.

Broos, K., Warne, M. S. J., Heemsbergen, D. A., Stevens, D., Barnes, M. B., Correll, R. L., & McLaughlin, M. J. (2007). Soil factors controlling the toxicity of copper and zinc to microbial processes in Australian soils. *Environmental Toxicology and Chemistry: An International Journal*, **26**(4), 583-590.

Bryjak, M., Wolska, J., & Kabay, N. (2008). Removal of boron from seawater by adsorption–membrane hybrid process: implementation and challenges. *Desalination*, **223**(1-3), 57-62.

Butt, B. Z., & Naseer, I. (2020). Nanofertilizers *Nanoagronomy* (pp. 125-152): Springer.

Cheng, B., Wang, C., Chen, F., Yue, L., Cao, X., Liu, X., ... & Xing, B. (2022). Multiomics understanding of improved quality in cherry radish (Raphanus sativus L. var. radculus pers) after foliar application of selenium nanomaterials. *Science of The Total Environment*, **824**, 153712.

Chinnamuthu, C., & Boopathi, P. M. (2009). Nanotechnology and agroecosystem. *Madras Agricultural Journal, 96*(1/6), 17-31.

Cieschi, M. T., Polyakov, A. Y., Lebedev, V. A., Volkov, D. S., Pankratov, D. A., Veligzhanin, A. A., . . . Lucena, J. J. (2019). Eco-friendly iron-humic nanofertilizers synthesis for the prevention of iron chlorosis in soybean (Glycine max) grown in calcareous soil. *Frontiers in plant science*, **10**, 413.

del Pino, J. N., Padrón, I. A., Martin, M. G., & Hernández, J. G. (1995). Phosphorus and potassium release from phillipsite-based slow-release fertilizers. *Journal of controlled release*, **34**(1), 25-29.

Delfani, M., Baradarn Firouzabadi, M., Farrokhi, N., & Makarian, H. (2014). Some physiological responses of black-eyed pea to iron and magnesium nanofertilizers. *Communications in soil science and plant analysis,* **45**(4), 530-540.

DeRosa, M. C., Monreal, C., Schnitzer, M., Walsh, R., & Sultan, Y. (2010). Nanotechnology in fertilizers. *Nature nanotechnology,* **5**(2), 91-91.

Eberl, D. (2002). Controlled-release fertilizers using zeolites. *US Geological Survey, Technology transfer*.

Eichert, T., Kurtz, A., Steiner, U., & Goldbach, H. E. (2008). Size exclusion limits and lateral heterogeneity of the stomatal foliar uptake pathway for aqueous solutes and water-suspended nanoparticles. *Physiologia plantarum,* **134**(1), 151-160.

El-Ramady, H., Abdalla, N., Alshaal, T., El-Henawy, A., Elmahrouk, M., Bayoumi, Y., . . . Fári, M. (2018). Plant nano-nutrition: perspectives and challenges. *Nanotechnology, food security and water treatment,* 129-161.

Farhana, Munis, M. F. H., Alamer, K. H., Althobaiti, A. T., Kamal, A., Liaquat, F., ... & Attia, H. (2022). ZnO nanoparticle-mediated seed priming induces biochemical and antioxidant changes in chickpea to alleviate Fusarium wilt. *Journal of Fungi*, **8**(7), 753.

Fansuri, H., Pritchard, D., & Zhang, D.-K. (2008). Manufacture of Low-Grade Zeolites from Fly Ash for Fertiliser Applications.

Fernández, V., & Eichert, T. (2009). Uptake of hydrophilic solutes through plant leaves: current state of knowledge and perspectives of foliar fertilization. *Critical Reviews in Plant Sciences,* **28**(1-2), 36-68.

Ghafariyan, M. H., Malakouti, M. J., Dadpour, M. R., Stroeve, P., & Mahmoudi, M. (2013). Effects of magnetite nanoparticles on soybean chlorophyll. *Environmental science & technology,* **47**(18), 10645-10652.

Ghani, M. I., Saleem, S., Rather, S. A., Rehmani, M. S., Alamri, S., Rajput, V. D., ... & Liu, M. (2022). Foliar application of zinc oxide nanoparticles: An effective strategy to mitigate drought stress in cucumber seedling by modulating antioxidant defense system and osmolytes accumulation. *Chemosphere,* **289**, 133202.

Ghorbani, H. R. (2014). A review of methods for synthesis of Al nanoparticles. *Orient. J. chem,* **30**(4), 1941-1949.

Ghoto, K., Simon, M., Shen, Z. J., Gao, G. F., Li, P. F., Li, H., & Zheng, H. L. (2020). Physiological and root exudation response of maize seedlings to TiO 2 and SiO 2 nanoparticles exposure. *BioNanoScience*, **10**, 473-485.

Gupta, G., Borowiec, J., & Okoh, J. (1997). Toxicity identification of poultry litter aqueous leachate. *Poultry Science,* **76**(10), 1364-1367.

Hershey, D., Paul, J., & Carlson, R. (1980). Evaluation of potassium-enriched clinoptilolite as a potassium source for potting media. *HortScience,* **15**(1), 87-89.

Janmohammadi, M., Sabaghnia, N., & Ahadnezhad, A. (2015). Impact of silicon dioxide nanoparticles on seedling early growth of lentil (Lens culinaris Medik.) genotypes with various origins. *Agriculture & Forestry/Poljoprivreda i Sumarstvo,* **61**(3).

Kithome, M., Paul, J., Lavkulich, L., & Bomke, A. (1998). Kinetics of ammonium adsorption and desorption by the natural zeolite clinoptilolite. *Soil Science Society of America Journal,* **62**(3), 622-629.

Kottegoda, N., Munaweera, I., Madusanka, N., & Karunaratne, V. (2011). A green slow-release fertilizer composition based on urea-modified hydroxyapatite nanoparticles encapsulated wood. *Current science,* 73-78.

Kumar, Y., SINGH, K. T. T., & RALIYA, R. (2021). Nanofertilizers and their role in sustainable agriculture. *Annals of Plant and Soil Research,* **23**(3), 238-255.

Kurepa, J., Paunesku, T., Vogt, S., Arora, H., Rabatic, B. M., Lu, J., . . . Smalle, J. A. (2010). Uptake and distribution of ultrasmall anatase TiO2 Alizarin red S nanoconjugates in Arabidopsis thaliana. *Nano letters,* **10**(7), 2296-2302.

Lee, W. M., An, Y. J., Yoon, H., & Kweon, H. S. (2008). Toxicity and bioavailability of copper nanoparticles to the terrestrial plants mung bean (Phaseolus radiatus) and wheat (Triticum aestivum): plant agar test for water-insoluble nanoparticles. *Environmental Toxicology and Chemistry: An International Journal,* **27**(9), 1915-1921.

Lin, D., Tian, X., Wu, F., & Xing, B. (2010). Fate and transport of engineered nanomaterials in the environment. *Journal of environmental quality,* **39**(6), 1896-1908.

Liu, R., & Lal, R. (2014). Synthetic apatite nanoparticles as a phosphorus fertilizer for soybean (Glycine max). *Scientific reports,* **4**(1), 1-6.

Liu, R., & Lal, R. (2015). Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions. *Science of the total environment,* **514**, 131-139.

Ma, X., Geiser-Lee, J., Deng, Y., & Kolmakov, A. (2010). Interactions between engineered nanoparticles (ENPs) and plants: phytotoxicity, uptake and accumulation. *Science of the total environment,* **408**(16), 3053-3061.

Malakouti, M. J. (2008). The effect of micronutrients in ensuring efficient use of macronutrients.

Turkish Journal of Agriculture and Forestry, **32**(3), 215-220.

Mazhar, M. W., Ishtiaq, M., Maqbool, M., & Akram, R. (2023). Seed priming with zinc oxide nanoparticles improves growth, osmolyte accumulation, antioxidant defence and yield quality of water-stressed mung bean plants. *Arid Land Research and Management*, **37**(2), 222-246.

Naderi, M., & Danesh-Shahraki, A. (2013). Nanofertilizers and their roles in sustainable agriculture. *International Journal of Agriculture and Crop Sciences (IJACS),* **5**(19), 2229-2232.

Nagula, S., & Usha, P. (2016). Application of nanotechnology in soil and plant system with special reference to nanofertilizers. *Advances in Life Sciences,* **1**(14), 5544-5548.

Nair, R., Varghese, S. H., Nair, B. G., Maekawa, T., Yoshida, Y., & Kumar, D. S. (2010). Nanoparticulate material delivery to plants. *Plant science,* **179**(3), 154-163.

Nekrasova, G., Ushakova, O., Ermakov, A., Uimin, M., & Byzov, I. (2011). Effects of copper (II) ions and copper oxide nanoparticles on Elodea densa Planch. *Russian Journal of Ecology,* **42**(6), 458-463.

Noreen, S., Fatima, Z., Ahmad, S., Athar, H.-u.-R., & Ashraf, M. (2018). Foliar application of micronutrients in mitigating abiotic stress in crop plants *Plant nutrients and abiotic stress tolerance* (pp. 95-117): Springer.

Palmqvist, N., Seisenbaeva, G. A., Svedlindh, P., & Kessler, V. G. (2017). Maghemite nanoparticles acts as nanozymes, improving growth and abiotic stress tolerance in Brassica napus. *Nanoscale research letters,* **12**(1), 1-9.

Pardha-Saradhi, P., Yamal, G., Peddisetty, T., Sharmila, P., Singh, J., Nagarajan, R., & Rao, K. (2014). Plants fabricate Fe-nanocomplexes at root surface to counter and phytostabilize excess ionic Fe. *Biometals,* **27**(1), 97-114.

Patra, S., Mishra, P., Mahapatra, S., & Mithun, S. (2016). Modelling impacts of chemical fertilizer on agricultural production: a case study on Hooghly district, West Bengal, India. *Modeling Earth Systems and Environment,* **2**(4), 1-11.

Preetha, P. S., & Balakrishnan, N. (2017). A review of nano fertilizers and their use and functions in soil. *Int. J. Curr. Microbiol. Appl. Sci,* **6**(12), 3117-3133.

Qureshi, A., Singh, D., & Dwivedi, S. (2018). Nano-fertilizers: a novel way for enhancing nutrient use efficiency and crop productivity. *Int. J. Curr. Microbiol. App. Sci,* **7**(2), 3325-3335.

Rahale, S. (2011). Nutrient release pattern of nanofertilizer formulation. *PhD (Agri.) Thesis. Tamilnadu Agricultural University, Coimbatore*.

Rico, C. M., Majumdar, S., Duarte-Gardea, M., Peralta-Videa, J. R., & Gardea-Torresdey, J. L. (2011). Interaction of nanoparticles with edible plants and their possible implications in the food chain. *Journal of agricultural and food chemistry,* **59**(8), 3485-3498.

Rop, K., Karuku, G. N., Mbui, D., Michira, I., & Njomo, N. (2018). Formulation of slow release NPK fertilizer (cellulose-graft-poly (acrylamide)/nano-hydroxyapatite/soluble fertilizer) composite and evaluating its N mineralization potential. *Annals of Agricultural Sciences,* **63**(2), 163-172.

Sabarudin, A., Oshita, K., Oshima, M., & Motomizu, S. (2005). Synthesis of cross-linked chitosan possessing N-methyl-d-glucamine moiety (CCTS-NMDG) for adsorption/concentration of boron in water samples and its accurate measurement by ICP-MS and ICP-AES. *Talanta,* **66**(1), 136-144.

Schmidt, R., & Szakál, P. (2007). The application of copper and zinc containing ion-exchanged synthesised zeolite in agricultural plant growing. *Nova Biotechnologica VII-I,* 57-62.

Sharonova, N., Yapparov, A. K., Khisamutdinov, N. S., Ezhkova, A., Yapparov, I., Ezhkov, V., . . . Babynin, E. (2015). Nanostructured water-phosphorite suspension is a new promising fertilizer. *Nanotechnologies in Russia,* **10**(7), 651-661.

Sheta, A., Falatah, A., Al-Sewailem, M., Khaled, E., & Sallam, A. (2003). Sorption characteristics of zinc and iron by natural zeolite and bentonite. *Microporous and Mesoporous Materials,* **61**(1-3), 127-136.

Singh, M. D. (2017). Nano-fertilizers is a new way to increase nutrients use efficiency in crop production. *International Journal of Agriculture Sciences, ISSN,* 0975-3710.

Solanki, P., Bhargava, A., Chhipa, H., Jain, N., & Panwar, J. (2015). Nano-fertilizers and their smart delivery system *Nanotechnologies in food and agriculture* (pp. 81-101): Springer.

Subramanian, K., Paulraj, C., & Natarajan, S. (2008). Nanotechnological approaches in nutrient management. *Nanotechnology Applications in Agriculture,* **61**, 37-42.

Subramanian, K., & Rahale, C. S. (2012). Ball milled nanosized zeolite loaded with zinc sulfate: a putative slow release Zn fertilizer. *International Journal of Innovative Horticulture,* **1**(1), 33-40.

Subramanian, K., & Tarafdar, J. (2011). Prospects of nanotechnology in Indian farming. *Indian J Agric Sci,* **81**(10), 887-893.

[Citation Rehman, H.U., Kausar, R., Nawaz, S., Akram, F., Asif, M., Ali, S., Kausar, S., Nadeem, M., Imran, M., Sarwar, M.A. (2023). Nutrient transformation through nanofertilizers in soil. *Biol. Clin. Sci. Res. J.,* **2023***:* 483. doi: https://doi.org/10.54112/bcsrj.v2023i1.483]

Subramanian, K. S., Manikandan, A., Thirunavukkarasu, M., & Rahale, C. S. (2015). Nano-fertilizers for balanced crop nutrition *Nanotechnologies in food and agriculture* (pp. 69-80): Springer.
Sun, Y., Wang, W., Zheng, F., Zhang, S., Wang, F., & Liu, S. (2020). Phytotoxicity of iron-based materials in mung bean: Seed germination tests. *Chemosphere*, **251**, 126432.
Supapron, J., Pitayakon, L., Kamalapa, W., & Touchamon, P. (2002). *Effect of zeolite and chemical fertilizer on the change of physical and chemical properties on Lat Ya soil series for sugar cane.* Paper presented at the Proceedings of the 17th WCSS Symposium, Aug.
Thakkar, K. N., Mhatre, S. S., & Parikh, R. Y. (2010). Biological synthesis of metallic nanoparticles. *Nanomedicine: nanotechnology, biology and medicine*, **6**(2), 257-262.
Tripathi, D. K., Singh, S., Singh, S., Mishra, S., Chauhan, D., & Dubey, N. (2015). Micronutrients and their diverse role in agricultural crops: advances and future prospective. *Acta Physiologiae Plantarum*, **37**(7), 1-14.
Wang, P., Lombi, E., Zhao, F.-J., & Kopittke, P. M. (2016). Nanotechnology: a new opportunity in plant sciences. *Trends in plant science*, **21**(8), 699-712.
Weng, B.-Q., Huang, D.-F., Xiong, D.-Z., Wang, Y.-X., Luo, T., Ying, Z.-Y., & Wang, H.-P. (2009). Effects of molybdenum application on plant growth, molybdoenzyme activity and mesophyll cell ultrastructure of round leaf cassia in red soil. *Journal of Plant Nutrition*, **32**(11), 1941-1955.
Xiumei, L., Fudao, Z., Shuqing, Z., Xusheng, H., Rufang, W., Zhaobin, F., & Yujun, W. (2005). Responses of peanut to nano-calcium carbonate. *Plant Nutrition and Fertitizer Science*, **11**(3), 385-389.
Yadav, T. P., Yadav, R. M., & Singh, D. P. (2012). Mechanical milling: a top down approach for the synthesis of nanomaterials and nanocomposites. *Nanoscience and Nanotechnology*, **2**(3), 22-48.
Yuvaraj, M., & Subramanian, K. (2019). Nano Zinc Micronutrient *Nanoscale Engineering in Agricultural Management* (pp. 151-163): CRC Press.
Zhou, J., & Huang, P. (2007). Kinetics of potassium release from illite as influenced by different phosphates. *Geoderma*, **138**(3-4), 221-228.
Zulfiqar, F., Navarro, M., Ashraf, M., Akram, N. A., & Munné-Bosch, S. (2019). Nanofertilizer use for sustainable agriculture: Advantages and limitations. *Plant Science*, **289**, 110270.

Declarations

Data Availability statement

All data generated or analyzed during the study are included in the manuscript.

Ethics approval and consent to participate

Not applicable

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Conflict of Interest

Regarding conflicts of interest, the authors state that their research was carried out independently without any affiliations or financial ties that could raise concerns about biases.

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