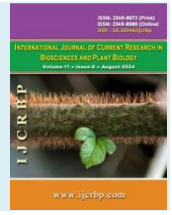




International Journal of Current Research in Biosciences and Plant Biology

Volume 11 • Number 8 (August-2024) • ISSN: 2349-8080 (Online)

Journal homepage: www.ijcrbp.com



Review Article

doi: <https://doi.org/10.20546/ijcrbp.2024.1108.003>

Nano-fertilizers revolutionizing Agriculture - A Review

P. Abithaa and Sugavaneshwaran Kannan*

Division of Agricultural Physics, ICAR-Indian Agricultural Research Institute, New Delhi 110012, India

*Corresponding author

Article Info

Abstract

Keywords:

Nano-fertilizer,
Controlled release,
Nutrient-use efficiency

Nano-fertilizers engineered nanoscale nutrient carriers—enable controlled release, targeted delivery, and high nutrient-use efficiency, overcoming limitations of conventional fertilizers. This review explores formulation strategies (e.g., membrane-coated urea, nano zeolite), uptake mechanisms via root and foliar pathways, and key influencing factors such as particle size, coatings, and soil properties. Agronomic benefits include enhanced crop growth, improved soil fertility, reduced nutrient loss, and heightened resilience to abiotic and biotic stresses. We also examine potential of nano fertilizers over conventional fertilizers. This comprehensive assessment underscores nano-fertilizers promise for sustainable agriculture when balanced with safety considerations.

• Received: 22 June 2024 • Revised: 14 July 2024 • Accepted: 30 July 2024 • Published Online: 6 August 2024

Introduction

One of the most important factors in guaranteeing global food security is agriculture, which will become even more important as the world's population grows—it is expected to reach 9.7 billion people by 2050. To meet the demand by the specified period, the food supply must increase to 70% (McDonald *et al.*, 2020). Widespread agricultural output intensification has been fuelled by the need for food to feed the world's rapidly growing population. The usage of agrichemicals, such as synthetic fertilizers and insecticides, has expanded significantly, contributing to notable increases in agricultural output (Callaghan *et al.*, 2022).

Conventional fertilizer use produced excellent crop

yields, but it also caused a number of environmental problems, including eutrophication from nitrogen leaching and soil property degradation (Sulaiman *et al.*, 2022). The increasing demand for food cannot be satisfied by current agricultural methods without the widespread use of fertilizers. However, the low nutrient usage efficiency of traditional fertilizers is an inherent limitation. For instance, important macronutrients like N, P, and K have relatively low NUEs; at present, they are 30–35%, 18–20%, and 35–40%, respectively, meaning that over half of the fertilizers that are administered are lost (Guo *et al.*, 2018).

According to scientific and agricultural research, an excessive reliance on chemical fertilizers—such as ammonia, urea, nitrate, or phosphate compounds—in

agricultural methods invariably causes serious harm to human health and the environment (Mahanty *et al.*, 2017).

The fact that proponents of alternative farming, such as "conservation agriculture," suggest conservation techniques that are neither novel nor workable because farming operates in an open system and conservation agriculture is therefore not very tenable thermodynamically in such a system, could be interpreted as a critique of the shortcomings of conventional technologies (Mukhopadhyay *et al.*, 2014). The issue of nutrient leaching in soil is resolved by foliar spray. It is recommended to use nano-urea instead of traditional fertilizers due to the possibility of increased groundwater pollution and urea fertilizer leaching (Kumar *et al.*, 2023).

Nanotechnology

The term "nano," which comes from the Greek word for "dwarf," is used in conjunction with technology to refer to operations that take place on a scale of 10⁻⁹ meters. A nanometer is a billionth of a meter, or 10 times the diameter of a hydrogen atom, or around 1/80,000 of the diameter of a human hair (Selin *et al.*, 2007). In general, there are two methods for creating nanoparticles: top-down and bottom-up methods. Using a top-down method, bigger entities produce nanomaterials and things without bouncing their atomic reactions. Generally speaking, the top-down strategy is used less frequently than the bottom-up approach (Nagula *et al.*, 2016).

Different landscapes, high nutrition demand, and a lack of technology make it impossible to satisfy these difficulties even with highly industrialized agriculture using conventional methods. Chemical use has not only had a negative impact on agriculture but also had detrimental impacts on the ecosystem and major health problems. Therefore, by lowering the use of pesticides and solving current issues, nanotechnology will be crucial in providing a well-run, sustainable agriculture sector (Kumari *et al.*, 2023).

Increased active ingredients and adjustable targeted distribution are provided by nano fertilizers and nano pesticides for crop protection and production. Through their beneficial effects on crop improvement and seed germination, nano micronutrients enlighten advances. To put it briefly, nano inputs open the door to novel

approaches to age-old problems as well as the potential for advantageous dosages and plant research (Dutta *et al.*, 2021).

Nano fertilizers

Fertilizer particles might be coated with nanomembranes to allow for the gradual release of nutrients. Slow-release nano fertilizers are used to counteract the misuse of inorganic fertilizers. Because of the slow rate of discharging supplements throughout crop production, these slowly released nano-fertilizers may be a fantastic alternative to dissolvable inorganic fertilizers. As a result, plants could absorb most of their nutrient needs without experiencing any losses (El-Saadony *et al.*, 2021). Sharifi (2016) discovered that the inoculum of *Bradyrhizobium japonicum* in conjunction with the foliar application of Zn-NPs enhanced soybean yield, oil amount, and quality.

Because the surface tension of nanomaterials on fertilizer particles is higher than that of conventional fertilizer particles, they are stronger and more effective at regulating nutrient release (Brady and Weil 1999). Tarafdar *et al.* (2012) shown that fertilizer particles might be coated with nanomembranes to allow for the gradual release of nutrients. Slow-release nano fertilizers are used to counteract the misuse of inorganic fertilizers. These slowly released nano-fertilizers could be a fantastic substitute for dissolvable inorganic fertilizers due to the sluggish rate at which supplements are produced throughout crop cultivation. As a result, plants could absorb most of their nutrient needs without experiencing any losses. Nano-fertilizers are regarded as a tried-and-true technique for boosting crop yields and delaying the release of nutrients, which lowers fertilizer application frequency and significantly improves nitrogen usage efficiency (NUE) (Khalid *et al.*, 2022).

Compared to conventional granular urea, nano urea liquid particles have a thousand times higher surface area to volume and range in size from 20 to 50 nanometers. Because of its microscopic size, Nano Urea is now more than 80% more available to crops (Tiwari *et al.*, 2021).

It has been demonstrated that nano-formulations release phosphate over 40–50 days, whereas conventional fertilizers only release nutrients for 10–12 days. Surface-modified zeolite may be a viable tactic to increase P use efficiency, which in conventional

systems barely surpasses 18–20% (Preetha *et al.*, 2017). By releasing fertilizer to the plant gradually, nanoporous zeolite allows the plant to absorb all of the nutrients from the fertilizer rather than just a small portion. Many molecules can fit within it and be released whenever the plant needs it because of its increased surface area. In addition to other slowly dissolving integrated nutrients that contain calcium, phosphorus, and a full range of minor and trace nutrients, its system of interconnecting tunnels and cages can be loaded with nitrogen and potassium (Naderi *et al.*, 2013). Therefore, nano-fertilizers aim to increase the effectiveness of nutrient utilization by leveraging the special qualities of nanoparticles. Nutrient transporters with nanoscale substrates, known as nano-fertilizers, can provide nutrients to the plant system for an extended amount of time without causing environmental harm (Subramanian *et al.*, 2017).

Nano biofertilizers

Nano-biofertilizer's bioorganic components, such as urea and microorganisms that promote plant growth, stimulate nitrogen-fixing capacity, phosphate solubility, and the production of more plant growth hormones, all of which improve the microbial condition of the soil (Shukla *et al.*, 2015). Biofertilizer coated with nanomaterials may improve the solubility and dispersion of insoluble nutrients in the soil, decrease soil fixation and absorption, increase the nutrients' bioavailability to plants and soil, and enable their gradual release with direct crop uptake and internalization (Nanderi *et al.*, 2013).

Thirugnanasambandan (2018) stated that because of the benefits of both nanoparticles and biofertilizer, nano-biofertilizer is ideal for the regulated, slow-release distribution of nutrients to plants, supplying the available nutrients to plants progressively over the course of a longer growing season.

This led to the need to find a nontoxic, environmentally friendly substitute in order to fulfil the objective of raising agricultural productivity without causing any unintended consequences. To ensure the biosafety of agriculture, bio- and nano fertilizers have been favoured over chemical fertilizers in recent decades (Dhir *et al.*, 2017). They are also carried to other plant sections by phloem cells via plasmodesmata, which have a diameter of 40 nm. They can be processed within the plant cell after attaching to carrier proteins via aquaporin, ion

channels, and endocytosis. Therefore, foliar application of nanoscale particles, like as nano-nitrogen, results in more effective nitrogen uptake and penetration.

Approach of nano fertilizers

The effectiveness of Nano fertilizers is determined by a number of parameters. The way that nano fertilizers are absorbed, transported, and accumulated, as well as the exposure route, greatly influences both intrinsic and extrinsic aspects in crops. Surface coatings and particle size are the main intrinsic elements influencing the effectiveness of NPs, while soil texture, pH, and organic matter are extrinsic factors that significantly influence the possible use of nano fertilizers in crops (Ma *et al.*, 2018). By slowing and regulating the release processes, they regulate the crops' nutrient accessibility, which benefits growers (Solanki *et al.*, 2015).

In addition to influencing plant growth and development, nitrogen fertilizers contribute to the maintenance of a sufficient supply of nutrient-dense food. These commercially available nano fertilizers (urea) disappear after about 75% application due to fast volatilization and leaching. Thus, the low usage of nitrogen fertilizers and the loss of nitrogen to the environment, which leads to eutrophication and excessive greenhouse gas emissions, are its drawbacks (Kahrl *et al.*, 2010). In order to help plants get nutrients at the proper time and location, nano-based fertilizers can be applied to them as nano-structured formulations (nutrient components) or by combining nano-structured elements into a carrier complex (Hussain *et al.*, 2023).

Additionally, less prilled urea may be applied, which would minimize salt buildup in the soil and lessen any remaining acidic effects. This would enhance the amount of nutrients that plants can access from the soil. Compared to applying fertilizers to the soil, foliar spray improves nutrient translocation and utilization in plants and increases nutrient absorption by 8–20 times. It promotes production, minimizes nutrient losses, improves photosynthetic efficiency, and nourishes plants (Kumar *et al.*, 2020).

Uptake mechanism

The plant's species, age, growth environment, physicochemical characteristics, stability, and manner of delivery all affect the uptake, translocation, and accumulation of nanoparticles. The cell wall's pore

diameter (5–20 nm) determines whether nanoparticles may pass through it (Fleischer *et al.*, 1999). As a result, nanoparticles or nanoparticle aggregates with a diameter smaller than the plant cell wall's pore size could pass through it with ease and reach the plasma membrane (Navarro *et al.*, 2008).

Agrochemicals are typically administered in three ways: soil amendment, seed treatment, and foliar spray. There are many repercussions from direct exposure to NPs, which is when they are combined with the soil, because localized concentrations rise more than those caused by foliar spraying (indirect exposure). Additionally, microbial communities in the rhizosphere or soil may be impacted by high exposure concentrations, which may limit plants' ability to absorb particles (Pallavi *et al.*, 2016). The process of dissolution and ion exchange reactions provides the nutrients in a slow-release manner that is driven by plant root need. The dissolution and ion exchange reaction are powered by the nutrients' adsorption by plant roots, which extracts nutrients as needed (Zhou *et al.*, 2007).

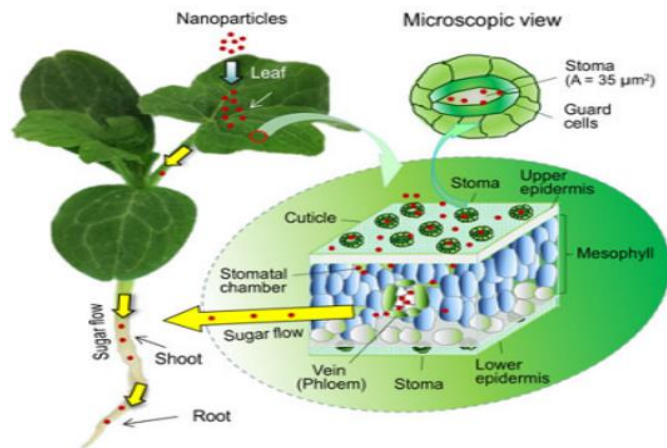


Figure.1 Entry, transport, translocation of Nano particles inside plant system. (Source: Wang *et al.*, 2013).

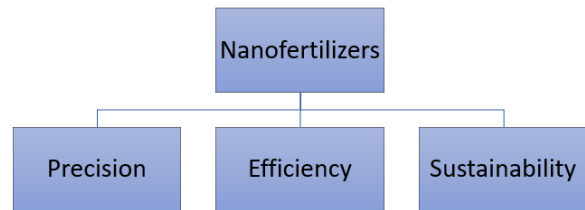
Advantages of Nano-fertilizers

Nanofertilizers provide numerous benefits over conventional fertilizers that were given by Thavaseelan and Priyadarshana. (2021) are discussed,

- ✓ A significant reduction in the risk of environmental pollution due to decreased nutrient losses.
- ✓ NFs' significantly higher diffusion rate and solubility in comparison to conventional synthetic fertilizers.

- ✓ Controlled nutrient release in NFs as opposed to chemical fertilizers, which is very spontaneous and rapid in the case of chemical fertilizers.
- ✓ NFs' lower requirement in comparison to synthetic fertilizers due to decreased loss and increased absorption.
- ✓ Improved soil fertility and the creation of a viable environment for microorganisms.
- ✓ Improved nutrient absorption and efficient use without increased losses.

Key benefits of Nanofertilizers



Effect on Plant Growth

According to Liang *et al.* (2013), in the maturity stage, the carbon nanoparticle treatments of 25, 75, and 125 mg pot⁻¹ enhanced leaf area by 6.64%, 19.51%, and 21.58%, respectively, in comparison to traditional fertilizer. Due to the enhanced availability of nitrogen within the plant system, a concentration of 0.4% nanospray had a substantial effect on plant growth (Velmurugan *et al.*, 2021). When zinc nanofertilizer was applied topically to pearl millet (*Pennisetum americanum* L.), the plant's dry biomass, shoot length, root length, and root area all increased noticeably (Tarafdar *et al.*, 2014). The use of nano-zinc increases growth indices such as plant height, leaf number, and fresh and dry weight of savory plants (Vafa *et al.*, 2015). By increasing the availability of Mg, Fe, and Zn nutrition, as well as the amounts of chlorophyll a, foliar spray with 2.5 mM nano-silicon reduced Cd stress in rice seedlings and reduced Cd buildup and translocation from root to shoot (Wang *et al.*, 2014).

Conclusion

The use of various nano-fertilizers can significantly increase agricultural output by reducing fertilizer costs and emission risks. Nanofertilizers offer regulated release and targeted dispersion because of their enhanced solubility, reactivity, and cuticle penetration (Avellan *et al.*, 2021). Moving forward, integrating

nano-fertilizers with precision farming practices backed by robust risk assessments, regulatory frameworks, and environmental monitoring will be essential to fully realize their potential while safeguarding ecosystem and human health.

Conflict of interest statement

Authors declare that they have no conflict of interest.

References

- Avellan, A., Yun, J., Morais, B. P., Clement, E. T., Rodrigues, S. M., & Lowry, G. V. (2021). Critical review: Role of inorganic nanoparticle properties on their foliar uptake and in planta translocation. *Environmental science & technology*, 55(20), 13417-13431.
- Brady, N. C. (1984). The nature and properties of soils.
- Dhir, B. (2017). Biofertilizers and biopesticides: eco-friendly biological agents. *Advances in environmental biotechnology*, 167-188.
- Dutta, D., & Bera, A. (2021). Nano fertilizer on sustainable agriculture-A review. *International Journal of Environment and Climate Change*, 11(8), 1-5.
- El-Saadony, M. T., Almoshadak, A. S., Shafi, M. E., Albaqami, N. M., Saad, A. M., El-Tahan, A. M., ... & Helmy, A. M. (2021). Vital roles of sustainable nano-fertilizers in improving plant quality and quantity-an updated review. *Saudi journal of biological sciences*, 28(12), 7349-7359.
- Fleischer, A., O'Neill, M. A., & Ehwald, R. (1999). The pore size of non-graminaceous plant cell walls is rapidly decreased by borate ester cross-linking of the pectic polysaccharide rhamnogalacturonan II. *Plant physiology*, 121(3), 829-838.
- Gogoi, B., Kanth, R. H., Bhat, T. A., Saxena, A., Khan, I. M., Wani, F. J., ... & Jibinsha, P. T. Efficacy of Nano Urea on Nitrogen Use Efficiency of Irrigated Maize under Temperate Ecology.
- Guo, H., White, J. C., Wang, Z., & Xing, B. (2018). Nano-enabled fertilizers to control the release and use efficiency of nutrients. *Current Opinion in Environmental Science & Health*, 6, 77-83.
- Hussain, B., Riaz, L., Javeed, K., Umer, M. J., Abbas, Y., Khan, S. W., ... & Ashraf, M. N. (2023). Use of nanoparticles and fertilizers in alleviating heavy metals and improving nutrients uptake in plants. In *Sustainable Plant Nutrition* (pp. 153-178). Academic Press.
- Kahrl, F., Li, Y., Su, Y., Tennigkeit, T., Wilkes, A., & Xu, J. (2010). Greenhouse gas emissions from nitrogen fertilizer use in China. *Environmental science & policy*, 13(8), 688-694.
- Khalid, U., Sher, F., Noreen, S., Lima, E. C., Rasheed, T., Sehar, S., & Amami, R. (2022). Comparative effects of conventional and nano-enabled fertilizers on morphological and physiological attributes of *Caesalpinia bonducella* plants. *Journal of the Saudi Society of Agricultural Sciences*, 21(1), 61-72.
- Kumar, A., Ram, H., Kumar, S., Kumar, R., Yadav, A., Gairola, A., & Sharma, T. (2023). A comprehensive review of nano-urea vs. conventional urea. *Int. J. Plant Soil. Sci*, 35, 32-40.
- Kumar, S. V., Srinivasan, G., Pazhanisamy, S., & Thanunathan, K. (2020). Effect of foliar nutrition on yield and quality of blackgram growing as augmenting crop under rice fallow condition. *International Journal of Current Microbiology and Applied Sciences*, 9(4), 2494-2499.
- Kumari, A., Rana, V., Yadav, S. K., & Kumar, V. (2023). Nanotechnology as a powerful tool in plant sciences: Recent developments, challenges and perspectives. *Plant Nano Biology*, 5, 100046.
- Liang, T. B., Yin, Q. S., Zhang, Y. L., Wang, B. L., Guo, W. M., & Wang, J. W. (2013). Effects of carbon nanoparticles application on the growth, physiological characteristics and nutrient accumulation in tobacco plants. *International journal of food, agriculture and environment (Print)*, 11(3-4), 954-958.
- Ma, C., White, J. C., Zhao, J., Zhao, Q., & Xing, B. (2018). Uptake of engineered nanoparticles by food crops: characterization, mechanisms, and implications. *Annual review of food science and technology*, 9(1), 129-153.
- Mahanty, T., Bhattacharjee, S., Goswami, M., Bhattacharyya, P., Das, B., Ghosh, A., & Tribedi, P. (2017). Biofertilizers: a potential approach for sustainable agriculture development. *Environmental Science and Pollution Research*, 24, 3315-3335.
- McDonald, R. I., Mansur, A. V., Ascensão, F., Colbert, M. L., Crossman, K., Elmqvist, T., ... & Ziter, C. (2020). Research gaps in knowledge of the impact of urban growth on biodiversity. *Nature Sustainability*, 3(1), 16-24.
- Mukhopadhyay, S. S. (2014). Nanotechnology in agriculture: prospects and constraints. *Nanotechnology, science and applications*, 63-71.
- Naderi, M. R., & Danesh-Shahraki, A. (2013). Nanofertilizers and their roles in sustainable agriculture.
- Naderi, M. R., & Danesh-Shahraki, A. (2013). Nanofertilizers and their roles in sustainable agriculture.
- Nagula, S. A. I. N. A. T. H., & Usha, P. B. (2016). Application of nanotechnology in soil and plant

- system with special reference to nanofertilizers. *Advances in Life Sciences*, 5(14), 5544-5548.
- Navarro, E., Baun, A., Behra, R., Hartmann, N. B., Filser, J., Miao, A. J., & Sigg, L. (2008). Environmental behavior and ecotoxicity of engineered nanoparticles to algae, plants, and fungi. *Ecotoxicology*, 17, 372-386.
- O'Callaghan, M., Ballard, R. A., & Wright, D. (2022). Soil microbial inoculants for sustainable agriculture: Limitations and opportunities. *Soil Use and Management*, 38(3), 1340-1369.
- Pallavi, Mehta, C. M., Srivastava, R., Arora, S., & Sharma, A. K. (2016). Impact assessment of silver nanoparticles on plant growth and soil bacterial diversity. *3 Biotech*, 6, 1-10.
- 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.
- Selin, C. (2007). Expectations and the Emergence of Nanotechnology. *Science, Technology, & Human Values*, 32(2), 196-220.
- Sharifi, R. S. (2016). *Application of biofertilizers and zinc increases yield, nodulation and unsaturated fatty acids of soybean. Zemdirbyste-Agriculture 103 (3): 251-258.*
- Shukla, S. K., Kumar, R., Mishra, R. K., Pandey, A., Pathak, A., Zaidi, M. G. H., ... & Dikshit, A. (2015). Prediction and validation of gold nanoparticles (GNPs) on plant growth promoting rhizobacteria (PGPR): a step toward development of nano-biofertilizers. *Nanotechnology Reviews*, 4(5), 439-448.
- Solanki, P., Bhargava, A., Chhipa, H., Jain, N., & Panwar, J. (2015). Nano-fertilizers and their smart delivery system. *Nanotechnologies in food and agriculture*, 81-101.
- Subramanian, K. S., & Thirunavukkarasu, M. (2017). Nano-fertilizers and nutrient transformations in soil. *Nanoscience and plant-soil systems*, 305-319.
- Sulaiman, N. K., & Misnan, S. H. (2022, September). Environmental sustainability through agriculture: perspectives of extension agents on adoption of sustainable practices. In IOP Conference Series: Earth and Environmental Science (Vol. 1082, No. 1, p. 012024). IOP Publishing.
- Tarafdar, J. C., Raliya, R., & Rathore, I. (2012). Microbial synthesis of phosphorous nanoparticle from tri-calcium phosphate using *Aspergillus tubingensis* TFR-5. *Journal of Bionanoscience*, 6(2), 84-89.
- Tarafdar, J. C., Raliya, R., Mahawar, H., & Rathore, I. (2014). Development of zinc nanofertilizer to enhance crop production in pearl millet (*Pennisetum americanum*). *Agricultural research*, 3(3), 257-262.
- Thavaseelan, D., & Priyadarshana, G. (2021). Nanofertilizer use for sustainable agriculture. *J Res Technol Eng*, 2(1), 41-59.
- Thirugnanasambandan, T. (2018). Advances and trends in nano-biofertilizers. Available at SSRN 3306998.
- Tiwari, K. N., Kumar, Y., Nayak, R. K., Rai, A., Singh, J., & Srivastava, S. S. A. (2021). Nano-Urea for enhancing yield and farmers profit with potato in Uttar Pradesh. *Ann Plant Soil Res*, 23(4), 495-500.
- Vafa, Z. N., Sirosmehr, A. R., Ghanbari, A., Khammari, I., & Falahi, N. (2015). Effects of nano zinc and humic acid on quantitative and qualitative characteristics of savory (*Satureja hortensis* L.).
- Velmurugan, A., Subramanil, T., Bommayasamy, N., Ramakrishna, M. K., & Swaranam, T. P. (2021). The effect of foliar application of nano urea (liquid) on rice (*Oryza sativa* L.). *J. Andaman Sci. Assoc*, 26(2), 76-81.
- Wang, S., Wang, F., & Gao, S. (2015). Foliar application with nano-silicon alleviates Cd toxicity in rice seedlings. *Environmental Science and Pollution Research*, 22, 2837-2845.
- Wang, W. N., Tarafdar, J. C., & Biswas, P. (2013). Nanoparticle synthesis and delivery by an aerosol route for watermelon plant foliar uptake. *Journal of nanoparticle research*, 15, 1-13.
- Zhou, J. M., & Huang, P. M. (2007). Kinetics of potassium release from illite as influenced by different phosphates. *Geoderma*, 138(3-4), 221-228.

How to cite this article:

Abithaa, P., and Sugavaneshwaran Kannan. 2024. Nano-fertilizers revolutionizing Agriculture - A Review. *Int. J. Curr. Res. Biosci. Plant Biol.*, 11(8): 12-17. doi: <https://doi.org/10.20546/ijcrbp.2024.1108.003>