Journal of
Plant Development Sciences
Meerut, India

MINI REVIEW

NANO-FERTILIZERS: POSSIBILITIES FOR THE SUSTAINABLE AGRICULTURE

Jitendra Singh and Beerendra Singh*

Department of Soil Science and Agricultural Chemistry
Veer Kunwar Singh, College of Agriculture, Dumraon
(Bihar Agricultural University, Sabour), Buxar-802 136, India
Email: beerendrasoil@gmail.com

Received-01.11.2023, Revised-14.11.2023, Accepted-24.11.2023

Abstract: Fertilizers and pesticides are less effective for many reasons, including inefficiency in distribution and use, and more energy requirement and water resources impacting agricultural ecosystems. Ensuring and maintaining food security is a global task, and the agricultural technologies must be changed and be effective over time due to negative factors such as climate change, population growth and decreasing in agricultural areas. Due to spiralling growth of population, the agriculture sector is facing a tremendous pressure for the food production and its economics. Nano-fertilizers may be important substances in crop production because decreasing per capita land-holding area and increasing population, conventional fertilizers having low nutrient use efficiency, causing of environmental pollution and more requirement of costly labour for their application. Recently nano-technology based products i.e. nano-fertilizers can improve plant growth and production by ensuring the distribution of nutrients in plant system. The framework is yet to be seen, because the main task in the coming years will be to create new and effective products in agriculture. They have more nutrient use efficiency. They should improve ecological biodiversity, sustainable agriculture and food quality. They should also economic viable. This study reviews the potentiality and possibilities of nano-fertilizers for improving plant performance under abiotic stress.

Keywords: Nano-fertilizers, Nano- particles, Sustainable agriculture, Nutrient, Soil fertility

INTRODUCTION

Chemical elements or compounds that are necessary for plant growth and its reproduction and metabolism are termed as essential plant nutrients. In its absence, the plant is unable to complete its normal life cycle, or it is part of some essential plant constituents or metabolites. Most of the plants can grow in most of the soils with having little amount of nutrition for complete its life cycle, without the addition of nutrients as fertilizer. However, for optimum plant growth, it is necessary to artificially modify soil fertility through the addition of fertilizers to promote vigorous growth and yield. This is done by supplying adequate water, light and nutrient through fertilizers or nano-fertilizers.

Nanotechnology is the understanding and control of matter of sizes roughly in the range of 1 to 100 nanometres. If one of the dimensions is in this range, it is considered a nanoparticle. Bulk materials when reduced to the nano-scale show some properties (melting point, physical strength, surface area, penetration power, electric conductance, optical effect, magnetism, etc.) which are different from what they exhibit on a macro-scale enabling unique applications. These materials can be either natural or engineered. At nano-scale, gravity would become less important, whereas surface tension and van der Waal forces would become more important (Tarafdar and Adhikari, 2015). Molecular modified or synthesized material with the help of nanotechnology used to nanoparticles for improving the fertility of soil for a better yield and increased crop quality are called as Nano-fertilizers. Nano-fertilizers are the nutrient carries in the dimension of 1-100 nm (De Rosa *et al*., 2006). Nano-fertilizer particles can be coated with nano-membranes that provide slow release of plant nutrients e.g., patented nano-composite containing N, P, K, micronutrients, mannose and amino acids that improve the nutrient uptake and utilization of nutrients by crops. Non-fertilizer in soil lead to reduce toxicity, increased efficiency of the nutrients in the soil, reduce negative effects caused by excessive consumption of fertilizers and reduce the frequency of application of fertilizers. Nano-fertilizers have emerged as a promising alternative that ensures high crop production and soil restoration. After successful scientific testing, preparations are being made to make nano-fertilizer on a large scale for agriculture by the Indian Farmer Fertilizer Cooperative (IFFCO).

*Corresponding Author

Commercial Nano-fertilizers

Many commercial nano-fertilizer are being used in crop production such as Zeolite based nano-fertilizer, Nanomang, Nanobor, Nanofert, Nanozinc, Nano-Gro fertilize, Nano-5, Nano-iron, organic nano-fertilizer, Bioumik, Nano NPK, Nano gypsum, Nano-lime Florican and Nano urea.

1. Nano Urea

Nanourea is the world's first nanourea and will be launched on May 31, 2021.Production of IFFCO Nano-urea liquid will begin in June 2021 and will be produced by IFFCO's NBRC in Karol, Gujarat, to the tune of 'Atmanirbhar Bharat' and 'AtmanirbharKrishi'.Recently, 90 crops were tested across the country and an average increase yield of 8% was achieved. This increases yield and improves food quality.A 500ml bottle of nanourea liquid contains 40,000 ppm nitrogen and can replace at least one bag of conventional urea.IFFCO prices nanourea at Rs. 240.00 per 500ml bottle, it is 10% cheaper than the price of a bag of urea to farmers.

2. Nano Organic Fertilizer

Nano-fertilizer has special functions such as high-water absorption, increasing efficiency from 20% to 200%, increasing photosynthesis by 3.5 times, and also increase leaf area by 70%.

3. Bio Nano-Fertilizer

Dr. Tarafdar of the Central Arid Zone Research Institute under the ICAR innovated nano-fertilizers using biosynthesis, for the first time in the world. Since it is complete bio-source, nano-fertilizer is eco-friendly fertilizer and improves carbon build-up, soil aggregation, and moisture retention. There is no health hazard and is suitable for all crop varieties including food grains, vegetables, and horticulture (Tarafdar *et al*., 2014).

4. Nano Gypsum

Gypsum is recommended for the reclamation of sodic soils but ability to reclamation depends on the fineness and solubility. The possibilities of nanotechnology in soil reclamation and to improve the efficiency of gypsum requirement, a maiden attempt was made to design nano gypsum for soil reclamation.

5. Nano Lime

Nano amendment for effective remediation of soil acidity - to optimize the rate of lime nanotechnological approach was used. Naturally available micro-size conventional CaCO3 particles were used for synthesis of nano crystals through top-down approach and encapsulated with nano-ionic surfactant (1% chitosan). It produced uniform nano-sized particles.

Role of Nano Fertilizers in Soil

The application of Nano-Fertilizers through soil irrigation ensures double advantages, i.e., soil improvement to optimize plant development productivity (Mahapatra *et al*., 2022) because the application of larger amounts of inorganic fertilizers to farming land may not be available to plants (Raliya *et al*., 2018; Tarafder *et al*., 2020). Therefore, Nano-Fertilizers could be a better approach for nutrient absorption by the roots. Various edaphic parameters regulate the range of mineral elements in the soil and may also change microbial colonies and rhizospheric microbial biomass to enhance soil fertility (Huiyuan *et al*., 2018; Wang *et al*., 2021), water availability, and plant growth (Mandal and Lalrinchhani, 2021; Rajput *et al*., 2021a; Verma *et al*., 2022).

Roots are a vital interaction site between plants and soil, allowing nutrients, water, and other physiologically important substances to be absorbed, and root development gets influenced by soil aeration, nutrient availability, pH, and soil texture (Fellet *et al*., 2021). The principal mechanism for nutrient accumulation and distribution from the soil to the aerial parts of plant tissues are diffusion and bulk (mass) flow. Diffusion is the movement of atoms, ions, molecules, generally from a region of higher concentration to a region of lower concentration. Diffusion is driven by a gradient in Gibbs free energy or chemical potential, while the bulk flow is found to be the pressure-driven distribution of solutes-water via xylem regulated by transpiration and soil nutrient availability (El-Saadony *et al*., 2021). The accumulation of NPs is associated with several ways of absorption/uptake via aerial surface, roots, grains, interacting atmospheric variables, rigidity of cell wall, and physiological, anatomical, and biochemical activities of the plant species/cultivars (Mittal *et al*., 2020). The surface tension of NPs on the surface of fertilizer particles is higher than that of ordinary fertilizer, which effectively regulates the release of nutrients (Brady and Weil, 1999; Adisa *et al*., 2019).

Role of Nano-Fertilizers on Crop Productivity and Quality

Nano-fertilizers play an important role in physiological and biochemical mechanisms by enhancing the availability of nutrients in crop plants. Nano NPK improves wheat leaf growth by increasing nutrient availability and stomatal dynamics with photosynthetic capacity (Verma *et al*., 2022), monitored in cotton and pearl millet (Tarafdar *et al*., 2014). Electron microscopic observations could detect the presence of NPs in the phloem route from leaf–stem–roots (Abdel-Aziz *et al*., 2018). Zn NF applied to the leaves significantly boosted overall plant performance, including biomass (Vafa *et al*., 2015), photosynthetic pigments, and enzymatic activities (Seleiman *et al*., 2021). Zinc may activate enzymes associated with metabolic processes, i.e., glucose and protein metabolism, growth regulators, pollen production, and biological membrane integrity, affecting the synthesis of natural auxin (Wu and Li, 2022). Thus, growth-boosting hormones may get enhanced with the use of nano Zn fertilizer to improve photosynthetic pigments, plant length, biomass, soluble protein, and carbohydrates in maize

(Sharifi *et al*., 2016). TiO2 improves plant biomass, nitrogen assimilation, and photo-reduction activities of PS II and electron transport chain (ETC), also scavenging ROS (Janmohammadi *et al*., 2016). The aerosol-amended application was found to be more efficient than soil application on the uptake and accumulation of NPs in plants (Raliya *et al*., 2015) and the growth characteristics, namely, length of plants, branch numbers, grain weight, and biological yield were found to be upregulated (34-38%) using Zn+Fe NFs in pearl millet and sunflower (Sham, 2017).

Nano Zn has an excess surface area-to-volume ratio, which aids in improving Zn absorption and productivity. Nano Zn fertilizer requires ten times less than standard ZnSO4. Zinc complexed chitosan NPs enhanced Zn content in grains without affecting grain yield and quality, protein content, spikelets per spike, and 1,000 kernel weight (Dapkekar *et al*., 2018). Pomegranate fruit productivity may increase (21–46%) per plant after foliar use with nano Zn and boron (B). The application of TiO2 NPs as a foliar treatment affects the development of barley plants, boosting plant yield, and seed quality (Janmohammadi *et al*., 2016), while NPs improve fertilizer efficiency and raise grain production.

Advantages of Nano Fertilizers

1. Enhanced Nutrient Uptake: Nano fertilizers help plants absorb nutrients more effectively. Due to the nanoparticles' small size and large surface area, roots can penetrate them more easily and nutrients are more readily available for absorption. As a result, crop output is increased as is the efficiency of fertilizer use. (Hussain *et al*., 2016)

2. Controlled Release Mechanisms: Nano fertilizers may be designed with controlled release mechanisms to provide the plants with nutrients gradually and continuously. Through the use of this controlled release function, nutrient leaching is avoided and a consistent supply of vital micronutrients is provided to plants at all stages of their growth cycle.

3. Increased Bioavailability: The solubility and bioavailability of vital micronutrients can be increased by using nano-sized particles, which can overcome the drawbacks of conventional fertilizers. Thus, crops cultivated with nanoparticle fertilizers have greater nutrient contents, making them more wholesome for human consumption.

4. Environmental Sustainability: Nano fertilizers are environmentally sustainable substitutes for traditional fertilizers. Their exact targeting lessens the requirement for heavy fertilizer application, reducing the chance of nutrient runoff and water body pollution. This lowers production costs for farmers while simultaneously preserving the environment. (Kah and Hofmann, 2014)

Future Plan

Sustainable global food security seems to be a big issue in times to come. Therefore, innovative/ appropriate agricultural practices may be explored to acquire the target of food production under changing climate variables, rising population, and loss of arable land. The precision crop production must be eyed over the application of suitable NPs in diversified agricultural cropping systems using nano-agricultural input to strengthen plants' capabilities to be cultivated in various agroecological zones to address the challenges with opportunities. The comprehensive proteomic and metabolomic approaches are to be unlayered to correlate NPs-induced gene expression profile of crop plants integrated and regulated by the operation of nucleus genome (nDNA), chloroplast genome (cpDNA), and mitochondrial genome (mtDNA), which confers an overall plants' growth, development, physiological fitness/performance, and carbon concentrating metabolism, i.e., photosynthesis linked with phototransformation of light energy using PSII and PSI appears to play a crucial role in regulating photophosphorylation, CO_2 fixation, and plant productivity, all eventually results to improve agriculture production worldwide through various cropping systems (Zulfiqar *et al*., 2019; Aqeel *et al*., 2022; Kalwani *et al*., 2022; Mahapatra *et al*., 2022).

The plant–NP interactions in the field must be carefully examined at the molecular level to minimize phytotoxic effects to sustain the soil health, which may boost crop productivity and extend the ecofriendly ecosystem by discouraging huge application of conventional fertilizers. Therefore, our insight for nano-formulation and its application must be focused on soil and groundwater based on innovative, safe, and cost-effective updated interventions for agroecological sustainability to feed the future generations to ensure quality human resources. All these intrinsic abilities of plants may be made to understand the possibility of sustainable crop improvement to full-fill the need for healthy food for all future generations globally.

CONCLUSION

In forthcoming future, population the world will be increased thereby, we will be faced a shortage of food to feed the new people arriving. The development of agriculture can only be achieved by using modern technologies and efficient use of resources without reduction in crop yields. For this, nano-fertilizers have greater potential for achieving sustainable agriculture, especially in the developing countries. Nano-fertilizers reduce production costs, maximize profits and help in reduction of environmental pollution. This is just the beginning of a new era and there is a great need for adoption of the agricultural technology that will cope with the needs of the future generations.

REFERENCES

Abdel-Aziz, H. M. M., Hasaneen, M. N. A. and Aya, M. O. (2018). Foliar application of nano chitosan NPK fertilizer improves the yield of wheat plants grown on two different soils. *Egypt. J. Exp. Biol.* **14**, 63–72. doi: 10.5455/egyjebb.20180106032701
Google Scholar

Adisa, I. O., Pullagurala, V. L. R., Peralta-Videa, J. R., Dimkpa, C. O., Elmer, W. H., Gardea-Torresdey, J. L., *et al.* (2019). Recent advances in nano-enabled fertilizers and pesticides: a critical review of mechanisms of action. Environ. Sci.: Nano. 6, 2002–2030. doi: 10.1039/C9EN00265K
Google Scholar

Aqeel, U., Aftab, T., Khan, M. M. A., Naeem, M. and Khan, M. N. (2022).A comprehensive review of impacts of diverse nanoparticles on growth, development and physiological adjustments in plants under changing environment.Chemosphere.291, 132672.doi: 10.1016/j.chemosphere.2021.132672
Google Scholar

Brady, N. C. and Weil, R. R. (1999).The Nature and Properties of Soils. 12th Ed. London: Prentice Hall Publishers. p. 1–9, 453–536, 727, 739–740.
Google Scholar

Dapkekar, A., Deshpande, P., Oak, M. D., Paknikar, K. M. and Rajwade, J. M. (2018). Zinc use efficiency is enhanced in wheat through nano fertilization. Sci. Rep. 8, 6832.doi: 10.1038/s41598-018-25247-5
Google Scholar

De Rosa, M.R., Monreal, C., Schnitzer, M., Walsh, R. and Sultan, Y.(2010).Nanotechnology in fertilizers. *Nat. Nano-technol. J.*, **5**, 91-96.
Google Scholar

El-Saadony, M. T., ALmoshadak, A. S., Shafi, M. E., Albaqami, N. M., Saad, A. M., El-Tahan, A. *et al.* (2021). Vital roles of sustainable nano-fertilizers in improving plant quality and quantity-an updated review. *Saudi J. Biol. Sci*., **28**, 7349–7359.doi: 10.1016/j.sjbs.2021.08.032
Google Scholar

Fellet, G., Pilotto, L., Marchiol, L. and Braidot, E. (2021). Tools for nano-enabled agriculture: fertilizers based on calcium phosphate, silicon, and chitosan nanostructures. *Agronomy*,**11**, 1239.doi: 10.3390/agronomy11061239
Google Scholar

Huiyuan, G., Jason, C. W., Zhenyu, W. and Baoshan, X. (2018).Nano-enabled fertilizers to control the release and use efficiency of nutrients. *Curr.Opin. Environ. Sci. Health*, **6**, 77–83. doi: 10.1016/j.coesh.2018.07.009
Google Scholar

Hussain, I, Singh, N. B., Singh, A., Singh, H. and Singh, S. C. (2016).Green synthesis of nanoparticles and its potential application. *Biotechnology Letters*, **38**(4), 545-560.
Google Scholar

Janmohammadi, M., Amanzadeh, T., Sabaghnia, N. and Dashti, S. (2016). Impact of foliar application of nano micronutrient fertilizers and titanium dioxide nanoparticles on the growth and yield components of barley under supplemental irrigation. *Acta Agric. Slov.* **107**, 265–276. doi: 10.14720/aas.2016.107.2.01
Google Scholar

Kah, M. and Hofmann, T. (2014). Nano-pesticides research: Current trends and future priorities. *Environment International*, **63**, 224-235.
Google Scholar

Kalwani, M., Chakdar, H., Srivastava, A., Pabbi, S. and Shukla, P. (2022). Effects of nanofertilizers on soil and plant-associated microbial communities: Emerging trends and perspectives. Chemosphere. 287, 132107.doi: 10.1016/j.chemosphere.2021.132107
Google Scholar

Mahapatra, D. M., Satapathy, K. C. and Panda, B. (2022).Biofertilizers and nanofertilizers for sustainable agriculture: phycoprospects and challenges. *Sci. Total Environ*. 803, 149990.doi:10.1016/j.scitotenv.2021.149990
Google Scholar

Mahapatra, D. M., Satapathy, K. C. and Panda, B. (2022).Biofertilizers and nanofertilizers for sustainable agriculture: phycoprospects and challenges. *Sci. Total Environ*. 803, 149990.doi: 10.1016/j.scitotenv.2021.149990
Google Scholar

Mandal, D. and Lalrinchhani (2021). Nanofertilizer and its application in horticulture. J. Appl. Hortic. 23, 70–77. doi: 10.37855/jah. 2021. v23i01.14
Google Scholar

Mittal, D., Kaur, G., Singh, P., Yadav, K. and Ali, S. A. (2020). Nanoparticle-based sustainable agriculture and food science: recent advances and future outlook. Front. Nanotechnol.2, 579954.doi: 10.3389/fnano.2020.579954
Google Scholar

Rajput, V. D., Minkina, T., Kumari, A., Harish, Singh, V. K., Verma, K. K. *et al.* (2021a). Coping with the challenges of abiotic stress in plants: new dimensions in the field application of nanoparticles. Plants 10, 1221.doi: 10.3390/plants10061221
Google Scholar

Raliya, R., Nair, R., Chavalmane, S., Wang, W. N. and Biswas, P. (2015).Mechanistic evaluation of translocation and physiological impact of titanium dioxide and zinc oxide nanoparticles on the tomato (Solanum lycopersicum L.) plant. *Metallomics* **7**, 1584–1594. doi: 10.1039/C5MT00168D
Google Scholar

Raliya, R., Saharan, V., Dimkpa, C. and Biswas, P. (2018). Nanofertilizer for precision and sustainable agriculture: current state and future

perspectives. *J. Agric. Food Chem.*, **66**, 6487–6503 doi: 10.1021/acs.jafc.7b02178

Google Scholar

Seleiman, M. F., Almutairi, K. F., Alotaibi, M., Shami, A., Alhammad, B. A. and Battaglia, M. L. (2021). Nano-fertilization as an emerging fertilization technique: why can modern agriculture benefit from its use?.Plants.10, 2. doi: 10.3390/plants10010002

Google Scholar

Sham, S. P. (2017).Effect of foliar application of nano zinc particles on growth, yield and qualities of sunflower (Helianthus annus L.) M. Sc. (Agri.) Thesis. Dharwad, Karnataka, India: Univ. of Agric. Sci.

Google Scholar

Sharifi, R., Mohammadi, K. and Rokhzadi, A. (2016). Effect of seed priming and foliar application with micronutrients on quality of forage corn (Zea mays). *Environ. Exp. Biol*., **14**, 151–156. doi: 10.22364/eeb.14.21

Google Scholar

Tarafdar, J. C., Raliya, R., Mahawar, H. and Rathore, I. (2014).Development of zinc nanofertilizer to enhance crop production in pearl millet (Pennisetumamericanum). Agric. Res. 3, 257–262. doi: 10.1007/s40003-014-0113-y

Google Scholar

Tarafdar, J.C. andAdhikari, T.(2015).Chapter-27.Nanotechnology in soil science. In: Soil science an introduction, pp. 1-34

Google Scholar

Tarafder, C., Daizy, M., Alam, M. M., Ali, M. R., Islam, M. J., Islam, R. *et al.* (2020).Formulation of a hybrid nanofertilizer for slow and sustainable release of micronutrients. ACS Omega 5, 23960–23966. doi: 10.1021/acsomega.0c03233

Google Scholar

Vafa, Z. N., Sirousmehr, A. R., Ghanbari, A., Khammari, I. and Falahi, N. (2015).Effects of nano zinc and humic acid on quantitative and qualitative characteristics of savory (Saturejahortensis L.). *Int. J. Biosci*., **6**, 124–136. doi: 10.12692/ijb/6.3.124-136

Google Scholar

Verma, K. K., Song, X.-P., Joshi, A., Tian, D.-D., Rajput, V. D., Singh, M. *et al.* (2022). Recent trends in nano-fertilizers for sustainable agriculture under climate change for global good security. *Nanomaterials*, **12**, 173.doi: 10.3390/nano12010173

Google Scholar

Wang, J., Liu, L., Gao, X., Hao, J. and Wang, M. (2021). Elucidating the effect of biofertilizers on bacterial diversity in maize rhizosphere soil.PLoSONE. 16, e0249834. doi: 10.1371/journal.pone.0249834

Google Scholar

Wu, H. and Li, Z. (2022). Recent advances in nano-enabled agriculture for improving plant performance, *The Crop J*. **10**, 1–12. doi: 10.1016/j.cj.2021.06.002

Google Scholar

Zulfiqar, F., Navarro, M., Ashraf, M., Akram, N. A. and Munne-Bosch, S. (2019). Nanofertilizer use for sustainable agriculture: advantages and limitations. *Plant Sci*., **289**, 110270. doi: 10.1016/j.plantsci.2019.110270

Google Scholar