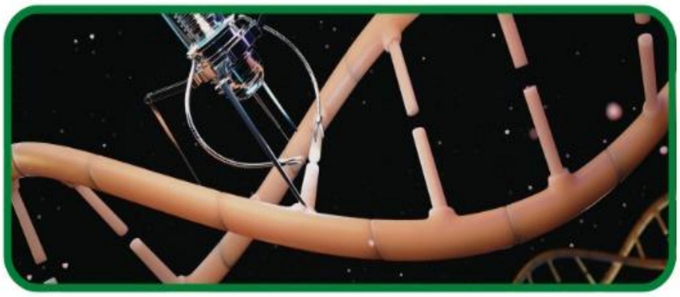
rebioin journal
OF BIOSCIENCES

USE OF NANOTECHNOLOGY TO ENHANCE THE EFFICIENCY OF TRADITIONAL AGRICULTURAL PRACTICES: THE KEY TO SUSTAIN TRADITIONAL AGRICULTURAL PRACTICE TO THE FUTURE



admin@reboin.com
www.rebioin.com

Use of Nanotechnology to Enhance the Efficiency of Traditional Agricultural Practices: The Key to Sustain Traditional Agricultural Practice to the Future

Bharath K M[1], S Nanjunda Swamy[1], Annie Jessica Toppo[2]
Department of Biotechnology, JSS Science and Technology University, Mysuru-570006, India[1].
Rapture Biotech Bengaluru (Rapture Biotech Pvt.Lmd)[2]
*Corresponding Author's Email: kmbharath36@gmail.com, nanjundaswamy@jssstuni.in

ABSTRACT

Global agriculture is expanding, to meet demand for food and to improve food safety and quality, which are declining daily as a result of the use of chemical pesticides and fertilizers. The environment and human health are experiencing serious problems as a result of these artificial fertilizers and pesticides. As a result, nanotechnology became an alternative where green synthesized nanoparticles offer the advantages of an eco-friendly approach. This review emphasizes how effectively plant-based nanoparticles can boost crop growth, enhance nutrient uptake, prevent pathogenicity, and prevent microbial infections. The mechanism by which plants interact with soil microorganisms, the toxicity of nanoparticles on plants, the limitations and drawbacks of nanotechnology, and their prospects for long-term sustainability are also covered in this paper.

KEYWORDS: Nanoparticles, nano-biofertilizers, nanoparticles, toxicity, nanotechnology.

1. INTRODUCTION

Rapid advancements in nanotechnology have an impact on all facets of the food system, including food production, processing, packaging, transportation, shelf life, and nutrient bioavailability [1].The multidisciplinary field of nanotechnology holds great promise for creating new instruments for treating plant diseases, identifying pathogens, and enhancing plant nutrient uptake [2]. In addition, nanotechnology is used in the creation of nano-fertilizers to improve their bioavailability and effectiveness while reducing their loss to the environment [3]. One of the areas of nano-research that is expanding the fastest is the use of nanotechnology in the agri-food industry. The use of nano-agrochemicals appears to be essential for advancing contemporary agriculture. Among the uses of nanotechnology are: 1) nano-formulations of agrochemicals for the application of fertilizers and pesticides for crop improvement; 2) the use of nano-sensors and nano-biosensors in crop protection for the detection of diseases and agrochemical residues; 3) nanodevices for plant genetic modification; 4) plant disease diagnostics; 5) animal health, animal breeding, and poultry production; and 6) postharvest management [4].

2. What are nanoparticles?

Nanoparticles are the extremely small particles which are measured between 1 to 100 nm in size. They exhibit distinct physical and chemical properties like optical, electrical, magnetic and chemical properties. This nano - particles are generally synthesized using plants and microorganisms to enhance their antimicrobial properties and eco-friendly nature.

3. Nano-biofertilizers

Agriculture has evolved in parallel with human evolution. Conventional agriculture demands the regular use of fertilizers, along with traditional agricultural practices, which can tremendously boost the crop growth, the yield, the productivity, and the nutritional value. Hence, chemical fertilizers have played an indispensable role in the growth of modern agricultural practices since the era of the green revolution. In the early years of the previous century, rapid mechanisation occurred in the field of agriculture whereas new technologies, such as marker-assisted breeding and transgenic crop production, were developed in the later years [5].

Although these advancements have helped to increase crop production phenomenally, they exert several harmful effects like diminishing the nutritional quality of soils, decreasing the resistance to pathogens and pests, and exert adverse effects on the environment. Out of the total amount of chemical fertilizers and pesticides applied, more than 50% has been estimated to remain unused as they accumulate in the soil and water bodies through leaching and mineralisation. Owing to the growing awareness of the harmful effects of fertilizers, the last decade has witnessed extensive research into biofertilizers, microbiomes, and soil health [6].

By 2050, there will be approximately 9.6 billion people on the planet and this will lead to an increased pressure on the available cultivable land in order to feed the world's ever-growing population. With the existing advancements and technology, the improvement of crop production and agricultural practices has reached its threshold, i.e., a stage has been reached where it would be nearly impossible to feed the projected population of the near future. Therefore, the development and application of smart agricultural practices using advanced, cutting-edge technologies are urgently needed for sustainable agriculture. This includes the need for the development of new and innovative fertilizers that have a very high efficiency and minimal disadvantages.

Nanotechnology and its associated applications have gained tremendous importance in the present age, as this branch of technology has greatly revolutionised modern science; moreover, this field of science is growing at an exponential rate. Nanomaterials are particles and materials that are handled at a nanoscale range of 1–100 nm. The novel properties of nanomaterials, combined with indigenous and traditional methods, may have tremendous innovative applications in various disciplines of science, including agriculture, which requires innovative methods in order to ensure global food security [7]. The challenge now lies in developing "sustainable and smart" agricultural advancements for rapid crop production. The idea of using nanotechnology in agriculture is not new; several reports that were published by the Department of Agriculture in the USA, Nanoforum, and others have emphasised nanotechnology-based research and application in the agricultural sector [8].

Moreover, nanostructured systems have been used in agriculture for the controlled release of pest-control agents, soil health monitoring, and providing nutrition to the plants. This method is part of the evolving science of precision agriculture, a system that goes hand-in-hand with sustainable agriculture and helps to reduce the energy demand and waste generation, where farmers use technology to efficiently utilise water, fertilizer, and other inputs. In addition, soil quality and fertility also play a crucial role in improving crop quality and yield. Nanofertilizers are nutrients that are encapsulated or coated within nanomaterial in order to enable controlled release, and its subsequent slow diffusion into the soil.

The use of nanoscale fertilizers may help to minimise nutrient loss by leaching/run-off and reduce its fast degradation and volatility, thus enhancing the nutrient quality and the fertility of the soil, and promoting crop productivity in the long run. Moreover, because of the high surface area tovolume ratio, and the high penetration ability of nanofertilizers, they may be a suitable alternative to chemical fertilizers. In addition, the use of nanofertilizers, or "nano-biofertilizers", can reduce the environmental hazard to a large extent. Several reports have revealed that nanofertilizers may boost the crop yield by stimulating seed germination, nitrogen metabolism, photosynthesis, protein and carbohydrate synthesis, and stress tolerance [9]. In addition to the other advantages, these need to be provided to the soil in a relatively lesser quantity, thus enhancing the ease of application and reducing the transportation costs.

However, similar to all other fertilizers, the use of nanofertilizers has certain limitations and disadvantages. In this review, we attempt to highlight the need for, and the application of, nanofertilizers for sustainable and smart agriculture. The subsequent sections briefly describe the synthesis of nanofertilizers and the mechanistic approach to how they enhance the soil fertility and improve the crop yield [10].

4. Nanopesticides

Whether they are functionalized nanocarriers for external stimuli or enzyme-mediated triggers, encapsulated in a matrix, or specially fixed on a hybrid substrate, nanopesticides are pesticides made in nanomaterials for use in agriculture. Because of their unique shape and characteristics, nanosized particles are believed to investigate pesticide activities in novel nanocarrier formulations based on a variety of materials, including silica, lipids, polymers, copolymers, ceramic, metal, carbon, and others [11].

Nanopesticide formulations have the potential to transform the management of diseases, weeds, and insects in crops by improving water solubility, bioavailability, and shielding agrochemicals from environmental deterioration [12]. However, the cytotoxicity and genotoxicity of the nanomaterials are also on the borderline.

The careless and illogical application of pesticides disrupts the ecosystem's equilibrium and puts everyone's health at risk. When pesticide residues are accidentally or occupationally consumed through food or water, the short-term (acute) and long-term (chronic) adverse effects can be fatal or result in disability-adjusted life years (DALY).

Children are more susceptible to long-term tissue and organ damage from pesticide exposure. Both the peripheral and central neurotoxicity, as well as the impact on the reduction of blood coagulation capacity, are significant causes for concern [13]. Indeed, the safe and sustainable growth of the already authorized use of nanoparticles in agriculture depends on a thorough evaluation of the advantages and disadvantages that affect the toxicity and activity of nanopesticides. The activity of nanotechnology as nanofertilizers and nanopesticides is shown in figure 1.

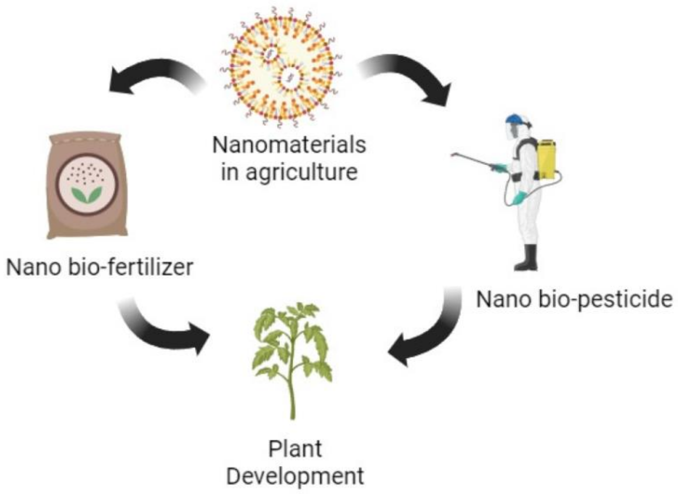


Figure 1: Use of nanomaterials as nanofertilizers and nanopesticides

5. Impact of Nanopesticides and Nanofertilizers on the Environment

Human health may be at risk, especially if nanomaterials are widely released into the environment and food chain [14]. Nanoparticles' surface area and other physicochemical characteristics may have a significant impact on how they change and become bioavailable as they spread throughout the environment. Nevertheless, there are currently no entirely complete systems in place to determine the possible impacts of pollution on the environment in relation to toxicity and nanoparticles [1]. Researchers and experts are concerned about the unsafe disposal of different nanoparticles (NPs) in large quantities (several hundred tons annually), despite the fact that nanotechnology offers many advantages.

According to recent normative documents, NPs can be found in a variety of controlled objects, including soils, water objects, atmospheric air, hydrobionts, algae, fungi, land plant and animal tissues, and more [15]. However, the possible adverse effects of NPs on human health have so far only been hypothesized and unsupported [16]. There is currently little information available on the ecotoxicological effects of nanopesticides, particularly with regard to the behavior and fate of these formulations in the environment.

Reducing the amount of pesticide required to ensure crop protection is one of the main motivators for the use of nanotechnology. This can be accomplished in a number of ways, including increased leaf adhesion, controlled release, targeted delivery, improved apparent solubility, and enhanced bioavailability [17]. Comparing conventional to nanopesticide formulations, studies found comparable toxicity, increased pesticidal toxicity [18], or similar toxicity at lower concentrations. Research indicates that the release can be slowed down by nanoformulations. Better pest targeting may be possible with nanoformulations. Photolysis [19], hydrolysis [20], and soil degradation [21] are just a few of the degradation processes that nanoformulations can prevent. One of the main problems is the current fertilizers' poor use efficiency. For example, volatilization can lose up to 50% of nitrogen fertilizer, and leaching can lose an additional 5% to 10%. Eutrophication is one of the serious environmental effects of fertilizer loss [22].

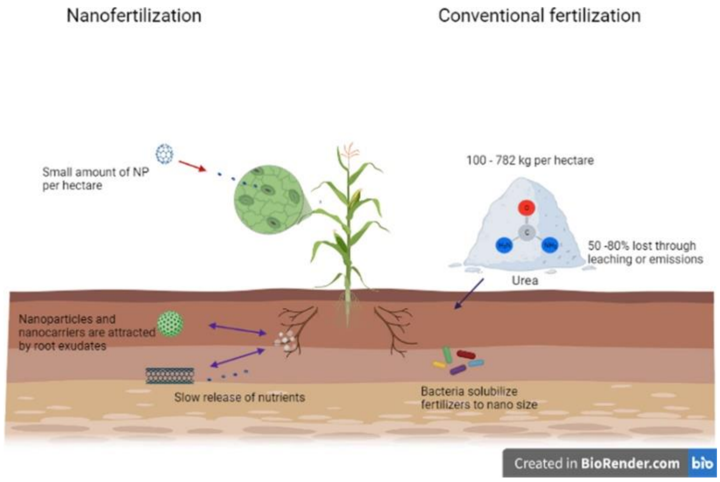


Figure 2: Impact of nanobiofertilizers and nanopesticides on plant

In the field of plant nutrition, nanotechnology is used to improve the efficiency of current fertilizers, either by limiting the loss of mobile nutrients to the environment (like nitrate) or by improving the delivery of elements that are not well bioavailable (like phosphorus and zinc). Alternative growth promoters like carbon nanotubes and TiO_2 are also being investigated. Depending on the role of the nanomaterials, and the nutrients in use, nanofertilizers can be separated into three different categories: 1) nanomaterials made of macronutrients, 2) nanomaterials made of micronutrients, and 3) nanomaterials acting as carriers for macronutrients. The first two categories comprise nanomaterials as nutrient themselves, whereas they are additives in the third category. While the third category is referred to as "nutrient-loaded nanofertilizers" or "nanomaterial-enhanced fertilizers," some researchers simply call the first two categories "nanofertilizers" [23]. When comparing the effectiveness of nanofertilizers and non-nano fertilizers based on germination, plant growth, or crop yield, the results are contrasted with those obtained using the corresponding conventional fertilizer.

Table 1: Accumulation of nanoparticles (NPs) in various crops.

	Crops	Concentration	Accumulation, mg/kg

NPs		mg/L * mg/kg	Root	Above-ground
Cu based	*Lactuca sativa* *Medicago sativa* *Oryza sativa* *Phaseolus vulgaris* *L. sativa* *Brassica oleracea* *B. juncea* *Triticum aestivum* *O. sativa* *Cucumis sativus* *Ipt-cotton* *B. juncea* *Zea mays* *Cajanus cajan* *Vigna radiata*	20 100 100 250 500 500 1000 1000 1000 1500 100 20 125	9941.3 3977.7 9000 800 3773 4448 >500 - 1544.1 500 7000 190.4 0.5 5.82 -	28.8 147.1 - - - 375 17.27 - - - 0.6 19.06 18.46
Ag based	O. sativa L. sativa Glycine max Solanum lycopersicum	1000 418.4 4000 250	20 - 2102 -	5 0.138 1135 50
TiO_2	T.aestivum S. lycopersicum	100 1000	110 -	- 250
$Mg(OH)_2$	Z.mays	1000	103	131
ZnO	Z.mays S. lycopersicum	100 1000	10 -	30 250

For categories 1, 2, and 3, the corresponding median efficacy gains of nanofertilizers over conventional fertilizers were 19%, 18%, and 29%. About 20% of category 2 nanofertilizers were less effective than their conventional counterparts. The majority of the original papers acknowledged and addressed the toxicity of various micronutrient elements at higher concentrations, which is most likely the cause of this.

Compared to conventional analogues, nanoagrochemicals can increase the toxicity of pesticides to their target pest by up to 20%. Additionally, research has indicated that nanofertilizers can boost crop yields by 20% to 30% when compared to conventional fertilizers. This means that reducing agrochemical use by 20% to 30% while still providing crop protection and nutrition could greatly reduce environmental contamination.

As of right now, no research has assessed how much of an environmental impact nanoagrochemicals have in comparison to traditional formulations. There is widespread worry about the possible harm that nanoparticles could cause to the environment and human health. Therefore, more research will be required to assess the new risks and advantages that nanoagrochemicals offer in comparison to current products [24]. Thus, it is necessary for present and future research to translate the mode of action of nanotechnology for plant protection or nutrition, as well as the design of more advanced products that could help lessen the negative effects of modern agriculture on the environment and human health and contribute to global food security.

In addition, comparing nanoagrochemicals to products already available on the market helps prevent irrational expectations or misplaced anxieties about the use of nanotechnology in agriculture. Innovation in agriculture is desperately needed to meet the growing demand for food while lessening its environmental impact. The creation of innovative products that are competitive and have the potential to improve the sustainability of agriculture in the future requires a substantial investment in research. It is hoped that responsible nanotechnology use will be crucial to achieving this objective [25].

6. Future prospect of nanotechnology

The use of nanotechnologies and NPs in the agriculture sector may help address sustainability concerns given the majority of challenges, particularly those related to climate change and an expanding global population. Actually, it is thought that the effective use of nanoscale carriers and nanoenable technology can decrease the quantity of materials used without compromising productivity. The use of NPs may result in less waste and more productive output.

Uncontrolled use of NPs, however, has the potential to enter soil and plant systems later on and continue to be an active part of the agricultural ecosystem.As a result, predicting the behavior of NPs in the environment and completely comprehending their fate and transport become difficult tasks.The analysis of the fate and transport of NPs is further complicated by the co-occurrence and parallel phenomena that occurred in the soil matrix, such as soil organic matter, plants, soil colloid, and micro-flora (microorganisms). Core metals and their size, speciation, surface charge and coatings, and the physical and chemical state of the environmental medium (such as pH, cation condition, and organic acid) are additional significant factors that impact the mobility, fate, and transport of NPs. Plant roots have the ability to accumulate NPs and then move them to different plant parts.

Accordingly, a thorough understanding of NPs' translocation depends on a number of factors, including the traits of NPs, plants, and their interactions. Translocations of NPs to the edible portion of plants may have negative health effects for people. Additionally, by preventing germination and root elongation, a class of NPs (such as Ag, CuO, and ZnO) was demonstrated to be phytotoxic to plants. The dissolution of NP toxic ions, the production of radicals as a result of NP interaction with plant or environmental media, and direct NP-plant interaction are all linked to the phytotoxicity effect of NPs.

A classical risk assessment procedure must be taken into consideration when it comes to considering the usage of NPs. Exposure assessment relies on the understanding and studying of the environmental fate of NPs once they release. To this end, there have been several limited factors to assess the exposure risk. It is also likely that fate and hazard endpoints are inadequately evaluated through comprehensive protocols that were developed only for specific types of chemicals. Overall, the current level of knowledge appears to be largely insufficient to address a reliable assessment for evaluating the risks associated with the use and fate of NPs [26,27].

However, prohibiting the application of NPs is only based on the general belief that toxicity does not make logical sense [28]. It is also note worthy to mention that some NPs, like other types of materials used for promoting the agriculture practices may purpose several benefits, including increased efficacy and reductions in applied amount and exposure to non-target organisms [24]. NPs can be engineered to be less harmful to the environment relative to conventional agrochemicals. Therefore, a fair assessment of NPs needs to be applied by looking at evaluating both the risks and benefits associated with their usage relative to current solutions [29].

7. CONCLUSION

From these studies we get to know that nanotechnology is a useful tool in agriculture. Considering the effects of chemical fertilizers on the environment nanobiofertilizers are considered as one of the alternative to synthetic fertilizers in the future. Even though there are many good impacts of nanoparticles are observed on the environment, there are some evil effects too. Researchers should also focus on the adverse effects of nanoparticles on nature which can give a clear picture to create a better user manual. The study of adverse effects of nanoparticles on environment gives us the suitable quantity at which we can use the nanoparticles.

Besides all the evil effects of nanoparticles their applications are giving more confidence. These nanoparticles can be used with biofertilizers and biopesticides to enhance their ability where the nanoparticles delivers the active compounds into the plants with the help of their size. The nutrients transported through nanoparticles were seen to be more effective according the studies (all the studies used in the paper). In this context, further biotechnological advances are required for a correct and safe application of nanoparticles in agriculture.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

ACKNOWDGEMENT

I would like to show my gratitude to all my guides, mentors, lab mates, friends and my family. To start of I sincerely thank the management of JSS Science and Technology University for providing an opportunity to identify and write on a topic which we are interested in. I extend my thanks to my HOD (Department of Biotechnology) Dr. Sanjay K R and my Intenal guide Dr. S Nanjundaswamy for their guidance and support.

I would like to express my gratitude to Mr. Jaspal Singh, Head of Rapture Biotech, Bengaluru for his support and for providing the necessary facilities and a conducive research environment to conduct the study.

My deepest thanks to Dr. Annie Jessica Toppo, my research guide, for her exceptional mentorship, insightful feedback, and unwavering support throughout my research journey. Her guidance has been instrumental in refining and shaping this paper.

REFERENCES

1. Bratovčić A. Nanomaterials in food processing and packaging, its toxicity and food labeling. Acta Scientific Nutritional Health. 2020;4(9):7-13.

2. Ghormade V, Deshpande MV, Paknikar KM. Perspectives for nano-biotechnology enabled protection and nutrition of plants. Biotechnology Advances. 2011;29(6):792-803.

3. Salama DM, Osman SA, Abd El-Aziz ME, Abd Elwahed MS, Shaaban EA. Effect of zinc oxide nanoparticles on growth, genomic DNA, production, and the quality of common dry bean (Phaseolus vulgaris). Biocatalysis and Agricultural Biotechnology. 2019;18:101083.

4. Sekhon BS. Nanotechnology in agri-food production: an overview. Nanotechnology, Science and Applications. 2014;20:31-53.

5. Stanley S. Biological nanoparticles and their influence on organisms. Current Opinion in Biotechnology. 2014;28:69-74.

6. Jampílek J, Kráľová K. Application of nanotechnology in agriculture and food industry: its prospects and risks. Ecological Chemistry and Engineering. 2015;22:321-361.

7. Colman BP, Wang SY, Auffan M, Wiesner MR, Bernhardt ES. Antimicrobial effects of commercial silver nanoparticles are attenuated in natural stream water and sediment. Ecotoxicology. 2012;21:1867-1877.

8. Keller AA, Lazareva A. Predicted releases of engineered nanomaterials: from global to regional to local. Environmental Science & Technology Letters. 2013;1:65-70.

9. Boxall A, Tiede K, Chaudhry Q, et al. Current and future predicted exposure to engineered nanoparticles. Safety of Nanomaterials Interdisciplinary Research Centre Report. 2007:1-3.

10. Buzea C, Pacheco II, Robbie K. Nanomaterials and nanoparticles: sources and toxicity. Biointerphases. 2007;2(4):MR17-MR71.

11. Agostini A, Mondragón L, Coll C, et al. Dual enzyme-triggered controlled release on capped nanometric silica mesoporous supports. ChemistryOpen. 2012;1(1):17.

12. Yadav RK, Singh NB, Singh A, Yadav V, Bano C, Khare S. Expanding the horizons of nanotechnology in agriculture: recent advances, challenges and future perspectives. Vegetos. 2020;33:203-221.

13. Kuhlbusch TAJ, Wijnhoven SWP, Haase A. Nanomaterial exposures for workers, consumers and the general public. NanoImpact. 2018;10:11-25.

14. Gill SS, Anjum NA, Hasanuzzaman M, et al. Glutathione and glutathione reductase: a boon in disguise for plant abiotic stress defense operations. Plant Physiology and Biochemistry. 2013;70:204-212.

15. Lanje AS, Sharma SJ, Pode RB. Synthesis of silver nanoparticles: a safer alternative to conventional antimicrobial and antibacterial agents. Journal of Chemical and Pharmaceutical Research. 2010;2:478-483.

16. Fernandes JP, Almeida CMR, Andreotti F, et al. Response of microbial communities colonizing salt marsh plants rhizosphere to copper oxide nanoparticles contamination and its implications for phytoremediation processes. Science of the Total Environment. 2017;581-582:801-810.

17. Kah M. Nanopesticides and nanofertilizers: emerging contaminants or opportunities for risk mitigation? Frontiers in Chemistry. 2015;3:64.

18. Griffiths BS, Philippot L. Insights into the resistance and resilience of the soil microbial community. FEMS Microbiology Reviews. 2013;37:112-129.

19. Simonin M, Martins JMF, Uzu G, Vince E, Richaume A. Combined study of titanium dioxide nanoparticle transport and toxicity on microbial nitrifying communities under single and repeated exposures in soil columns. Environmental Science & Technology. 2016;50:10693.

20. Simonin M, Cantarel AA, Crouzet A, et al. Negative effects of copper oxide nanoparticles on carbon and nitrogen cycle microbial activities in contrasting agricultural soils and in presence of plants. Frontiers in Microbiology. 2018;9:3102.

21. Gao Z, Karlsson I, Geisen S, Kowalchuk G, Jousset A. Protists: puppet masters of the rhizosphere microbiome. Trends in Plant Science. 2019;24:165-176.

22. Agathokleous E, Feng Z, Iavicoli I, Calabrese EJ. The two faces of nanomaterials: a quantification of hormesis in algae and plants. Environment International. 2019;131:105044.

23. Zhao ZB, He JZ, Geisen S, et al. Protist communities are more sensitive to nitrogen fertilization than other microorganisms in diverse agricultural soils. Microbiome. 2019;7:33.

24. Kah M. Nanopesticides and nanofertilizers: emerging contaminants or opportunities for risk mitigation? Frontiers in Chemistry. 2015;3:64.

25. Lowry GV, Avellan A, Gilbertson LM. Opportunities and challenges for nanotechnology in the agri-tech revolution. Nature Nanotechnology. 2019;14:517-522.

26. Haddad NM, Brudvig LA, Clobert J, et al. Habitat fragmentation and its lasting impact on Earth’s ecosystems. Science Advances. 2015;1:e1500052.

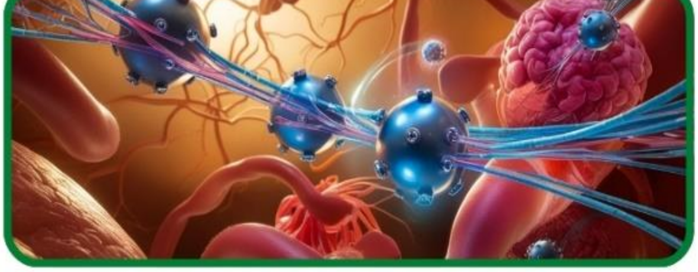
27. Goyette JO, Bennett EM, Maranger R. Low buffering capacity and slow recovery of anthropogenic phosphorus pollution in watersheds. Nature Geoscience. 2018;11:921-925.

28. Hébert MP, Fugère V, Gonzalez A. The overlooked impact of rising glyphosate use on phosphorus loading in agricultural watersheds. Frontiers in Ecology and the Environment. 2019;17:48-56.

29. Vitousek PM, Aber JD, Howarth RW, et al. Human alteration of the global nitrogen cycle: sources and consequences. Ecological Applications. 1997;7:737-750.

rebioin journal
OF BIOSCIENCES

USE OF NANOTECHNOLOGY TO ENHANCE THE EFFICIENCY OF TRADITIONAL AGRICULTURAL PRACTICES: THE KEY TO SUSTAIN TRADITIONAL AGRICULTURAL PRACTICE TO THE FUTURE



Plot no 977, GMS Road, near Balliwala Flyover, opposite Cubic Plaza, Dehradun, Uttarakhand 248001

admin@reboin.com

www.rebioin.com