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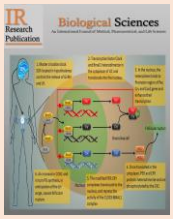

Nano-biofertilizers: Progressive evolution for sustainable agriculture

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ABSTRACT

The application of Nano-biotechnology for the development of fertilizer to enhance the nutritional kinetics of the plant-soil system for sustainable agricultural systems is being reviewed. Excessive use of synthetic fertilizers has caused deleterious effects on the soil microflora, it not only reduces its fertility but also causes lessened remuneration causing financial losses as well as side effects on the environment further causing degradation of biodiversity. Nanotechnology has become a promising area to deal with the above problems, especially in agriculture. With the help of Nano-biotechnology, a conjugated strategy comprising nanomaterials and bio-fertilizers can be achieved which will prove to be a unique, environmentally safe Nano-biofertilizer also having economic value. According to the existing literature, Nano-biofertilizer plays a significant role to modify plant and soil systems for the amelioration of agricultural productivity. Both Nanotechnology and bio-fertilizers work harmoniously due to microbial resurrection as well as nanomaterial coatings delivering higher captivity of soil moisture and vital nutrients of plant and it is because plant growth promoters inside the bioorganic components are generally present and it is either due to direct or indirect relation which can be easily related to various aspects like disease resistance, rhizoremediation and so on. Efforts are being made to review the bio-fertilizer formulations, which are based on nanotechnology with the motive to attain enhanced and sustainable crop production.

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Introduction

The ever-growing population and in parallel the demand for food is increasing day by day; this has led to a rise in the yield per unit area for crop production. Due to this, the increasing utilization of synthetic fertilizers in agriculture is taking place. Hence, it is now predominant to improve agriculture production and its management with ever degrading soil fertility [1]. Even though many types of fertilizers are readily available in the current

market, the origin of fertilizer can be traced back many years. Fertilizers can be either natural or synthetic, which when applied to a plant tissue for the fulfillment of basic nutrients in the form of micronutrients and macronutrients can both be essential regarding plant growth especially to overcome the deficiencies related to plant nutrients, but large-scale use of fertilizers can lead to environmental hazards [2]. Hence, the natural fertility of the soil is affected by consuming a higher amount of nitrogen fertilizers [3]. The issues related to chemical fertilizers and bio-fertilizers can be overcome by appropriately using the so-called next-generation technology i.e., Nanotechnology for the eco-friendly advancements in existing fertilizers technology [7]. Nanotechnology has emerged as a cutting-edge scientific discipline that has ushered in a new era of nano-agriculture, which aims to revolutionize agricultural cultivation and nutrition administration methods by employing a variety of revolutionary gadgets and products to boost crop output [9]. On the other hand, Nano-fertilizers are material elements that have at least one physical dimension in the range of 1–100 nm that can be generated from otherwise bulk materials [21]. The benefit of this technology can not only be used for enhancing crop productivity but also be used to extract the existing benefits of bio-fertilizers known as Nano-biofertilizers. Nano-biofertilizer is a product that contains nano-sized material with a specific microbial inoculant due to its nanoscale in nature which induces its application method that can provide timely and targeted nutrient delivery to the field crops while also improving the functional benefits of the bio-fertilizer component of the formulation. In general, it can be said that Nano-biofertilizers are orchestrated improvised forms of traditional fertilizers.

Progressive Evolution of Fertilizers

Increased crop yield and achieving proper food supply were possible due to the use of chemical fertilizers [3, 11]. Although inorganic fertilizers are fulfilling the food demands of society, their profound use causes so many problems related to health and the environment which is irredeemable. This problem arises due to extensive use of chemicals, The literature review assured that during the year 1998-1999, nitrogen (N) consumption was 81, phosphorus (P) 14, and potassium (K) 18 million tonnes /year respectively. It also shows that cereal production utilized more than 50% of the nutrients, 10 to 12% was used for crops like oilseed with the almost same amount for grassland and commodities, followed by root crops and for fruit & vegetable production comprising of around 5% each [2].

In the decade 1950 comparatively, a smaller number of fertilizers were needed for crop production which kept on increasing each decade but in the present scenario, the dependency on fertilizer increased by 70% due to less soil natural fertility. With the rise in population growth, the demand for plant nutrients is increasing continuously [3]. According to researchers, by 2050 the world population is expected to grow by more than double [4]. As chemical fertilizers understandably increase crop productivity and yield but due to their low metabolic properties, they can be hardly suggested for future agriculture perspectives. The Utilization of inorganic fertilizers is decreasing day by day as they reduce organic matter contents and reduce absorbance of nutrients like 0-25% for phosphorus and 20-50% for nitrogen is observed [5]. Although chemical fertilizers are a major contributor to the world's sufficient agricultural production, their misuse is posing serious problems for current and future generations, such as contaminated air, water, and soil, degraded lands, depleted soils, and increased greenhouse gas emissions. These synthetic fertilizers are posing a threat not only to our environment, but also to humans, animals, and microbiological life [26]. Water eutrophication is a major negative impact of intensive fertilizer use (mostly nitrogen and phosphorus). Phosphate is the most important factor in eutrophication. Phosphorus levels in surface waters should be less than 50 g/liter. When there is an increase in biomass growth, nitrogen can become a factor in eutrophication [27]. High rates of chemical fertilizer application for agricultural production increase greenhouse gas emissions, eroding the protective ozone layer and exposing humans to harmful ultraviolet rays [22]. Agriculture is the primary source of anthropogenic N2O emissions, accounting for 60% of total emissions. [23]. During the production of nitrogenous fertilizer, greenhouse gases such as CO2, CH4, and N2O are created. Overuse of chemical fertilizers can cause soil acidification and soil crust, diminishing organic matter, humus, and beneficial organisms, inhibiting plant growth, changing soil pH, increasing pests, and even contributing to greenhouse gas emissions. Soil acidity reduces crop phosphate absorption, raises harmful ion concentrations in the soil, and slows crop growth [28]

Due to the above-mentioned issues; the contribution of chemical fertilizers becomes less for the growth of the plant and more for its deposition in soil.

As discussed above chemical fertilizers helped enhance the productivity of crops but at the same time, they had limitations of their own. Bio-fertilizers came up as a better alternative to chemical fertilizers owing to their biodegradable properties. The

Table 1. Groups of currently using Bio-fertilizers

S.No.	Groups of Bio-fertilizers	Examples	References
1	Plant Growth Promoting Rhizobacteria	*Bacillus megaterium, Anabaena, Azolla, Bradyrhizobium, Bacillus polymyxa, Rhizobium* and *Sinorhizobium*	[29]
2	Nitrogen fixing Bio-fertilizers	Azorhizobium ,rhizobium, Bradyrhizobium, Azolla and Cyanobacteria	[30]
3	Phosphate Solubilizing Bio-fertilizers	*Bacillus subtilis,Pseudomonas straita, Penicillium sp., Aspergillus awamori*	[31]
4	Potassium Solubilizing Bio-fertilizers	*Bacillus* spp., *Aspergillus niger, Arthrobacter* spp., *Cladosporium*, *Sphingomonas aminobacter and Bacillus pseudomycoides*	[32]

formation of bio-fertilizers involves many important root-associated microorganisms which include fungal mycorrhizae, azospirillum, blue-green algae (BGA), and bacillus species. As mentioned in table 1 the groups of bio-fertilizers are used nowadays for the betterment of the crop and agriculture. These are widely used to elevate and enable the provisioning of nourishment for crops by improvising the nitrogen fixation ability and solubilization of the complicated organic matter into a simpler form [16]. Given the advantages of bio-fertilizers over traditional fertilizers, it is easy to assume that bio-fertilizers can easily overcome the deficiencies, but it is noteworthy that it has concerns of their own. Issues like amassing of salts, metals, and other components including nutrients itself can lead to unfavorable consequences on the growth of the plant [11].

Bio-fertilizers are an excellent way to boost crop output. Bio-fertilizers have been utilized to deliver necessary nutrients to plants and greatly boost their yield in recent years. These are environmentally friendly, cost-effective, give the plant a natural habitat, strengthen the plant's defense system, and protect the plant from drought, acidity, and other harsh conditions. The benefits of using bio-fertilizers outweigh the disadvantages of using other toxic chemical fertilizers [32]. Bio-fertilizer consumption is expected to rise in the future, indicating a more environmentally friendly and sustainable agriculture system. For the successful development and deployment of bio-fertilizers, however, an understanding of soil parameters, field environment, and strain specificity is required.

Recent breakthroughs in molecular biology, biotechnology, genetic engineering, microbial taxonomy, and nanotechnology have all contributed to the development of bio-fertilizers that are more efficient, competitive, and have numerous functions [33]. Bio-fertilizers can help keep crops productive while reducing an environmental impact and can be a good alternative to chemical fertilizers. In this subject, more research is needed to study and identify soil-specific strains, learn more about bio-fertilizer composition, and use biotechnological technologies to improve current strains.

The Great hustle undertaken by the researchers made it possible to replicate synthetic fertilizers with some eco-friendly fertilizers viz., nanotechnology. Using the combination of mineral nano nutrients and bio-fertilizers came up as a promising approach, i.e., Nano-biofertilizers. It has lowered the haphazard applications of agrochemicals and helped to validate integrated nutrient management for sustained crop productivity [6]. Nano-biofertilizers are now seen as the future of agriculture and are a perfect alternative to existing technologies which have some or the other drawback or limitations [7]. Bioorganic components of a Nano-biofertilizer benefitted the soil in various modes like modulating its nutrient efficacy and beneficial microflora.

Contribution of Nano-biofertilizers to crop improvement

The method of formation of Nano-biofertilizers, i.e., coated with a surface of bio-fertilizers by nanoparticles helps enhance the surface area in the case of nutrients further allowing its stability and increasing the active uptake of soil nutrients [8].

Optimization of photosynthesis helps escalate the growth of crops and the transfer of all important nutrients to various parts of the plant escalates the productivity of the crop [9]. When considering promoting the crops, Nano-biofertilizers being developed by entrapping bio-fertilizers have been highly effective especially when as a fertilizer NPs used [10]. Nano-biofertilizers can hence be used to promote both pocket and eco-friendly approaches.

To date, numerous investigations through extensive experimentation have been performed which have involved the review of chemical fertilizers and their repercussions on the ecosystem of agriculture and related areas [12, 13]. Multiple impacts in terms of groundwater pollution, decrease in soil fertility, acidification in the soil, pollution in the atmosphere, degradation in biodiversity, and so on are the cornerstone of problems related to chemical fertilizers [14]. Owing ill effects related to chemical fertilizers, especially when overused, have shoved the society to find an alternative to chemical fertilizers that too some eco-friendly approach can lead the society towards a greener and healthier habitat [9].

After inspection of all limitations by researchers, they started concentrating on modern technologies based on nanoparticles and bio-fertilizers [15]. This innovative approach gives rise to a Nano-biofertilizer to deal with a major issue related to the production of crops, sustainability, and eco-safety [18]. This technique involves the live formulation of microorganisms that promote bacteria enhancing plant growth which is further coated with nanoscale polymer a technique famously called nanoencapsulation [17, 19].

Many nanomaterials are used for encapsulation of organic nutrients, this can include but is not limited to chitosan and zeolite [20]. One of the best features of nanoencapsulation technology is flexibility and this can be used for the protection of bio-fertilizer components that contain PGPR (plant growth-promoting rhizobacteria) and this has led to an increase in the shelf life and also helped to enable the controlled release of the mechanism called as PGPR [21].

Different formulations have been designed for enhancing the crop production viz. (nano-Zn + bio-fertilizer) which reported the enhancement of physiochemical properties of sugarbeet plant and by application of combination (nanopharmax + humic acid) in black cumin may also enhance the nutritional ingredient in cumin [22, 23]. It has been reviewed that the application of Nano-biofertilizer with specific bio-inoculant namely Azetobacter strain, *Pseudomonas putida, Pantoea agglomerans* strain P5 increases the concentration of nutrients and elevated level of pigments content also enhances the other parameters like photosynthetic productivity, leaf area, sucrose content, etc. is observed on distinct parts of the plants [6].

It has been shown that manufactured nanoparticles can get up in many environmental compartments such as soils, water, air, and plants as a result of improper handling or unintentional activities. The earth is shown to be the primary and final sink for these nanoparticles, whereas the air is the secondary sink. These nanoparticles may be hazardous to soil organisms and cultivated plants under certain soil conditions, and many nanoparticles may be transported and uptaken by plants, resulting in phytotoxicity.[24]

Numerous studies have shown that many nanoparticles can cause phytotoxicity by producing reactive oxygen species, causing oxidative stress, protein and DNA damage, and lipid peroxidation in plants [25].

Conclusion

Although extensive utilization of fertilizer increases crop production it also affects the fertility of the soil by changing its chemical and physical properties which in turn not only pollutes the environment but also causes soil acidification, and eutrophication, and affects other plant's nutritional qualities. Therefore, it can be concluded that it is the need of the hour to develop and promote an environmentally friendly technique for sustainable agricultural products which will lead to minimum or zero side effects. Nano-bio-fertilizers can be considered a promising and futuristic approach for sustainable agricultural management as well as appropriate soil health. The inclusion of nano-based technology in the existing methodology will not only procure more targeted farming but also enhance crop productivity; it will also lead to better nutrient availability and uptake for plant growth. In this review, it has been observed that Nano-biofertilizers can come up as an alternative to traditional fertilizers and this will lead to enhanced capabilities for nutrients absorption and reduced loss of nutrients compared to traditional methods, further improvising the plant growth and its productivity. Additionally, low doses of requirements can also be achieved. Therefore, it can be concluded that the future of nanotechnology-based farming will improve the existing methodologies of fertilizers and effectively farming as well. It will also lead towards a clean and pocket-friendly mechanism leading us to sustainable and greener agriculture development.

Contribution of authors

Both the author drafted and revision the paper

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Not available

Conflict of interest

The authors declare that they have no conflict of interest.

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