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Prospect of nano-fertilizers in agriculture: An overview

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Abstract

A new paradigm in nutrient delivery to crops is being introduced by the use of nanofertilizers in agriculture, opening up a number of transformative opportunities. In order to precisely manage nutrient release, solubility, and interactions with plants and soil, nanofertilizers are created at the nanoscale. This level of accuracy enables plants to absorb nutrients in the best possible way, improving crop development, yield, and overall productivity. The waste frequently associated with conventional fertilizers is minimized with nanofertilizers, which also lessen the environmental impact of nutrient runoff and leaching. Furthermore, by ensuring that nutrients are accessible to plants for longer periods of time and reducing the need for frequent reapplication, their controlled release qualities support sustainable agricultural practices. The use of nanofertilizers is also consistent with the ideas of precision agriculture because these substances can be designed to release nutrients at particular growth stages, addressing the particular requirements of plants at various stages of development. This tailored strategy avoids excessive application, optimizes nutrient delivery, and lowers costs for farmers. Despite these encouraging benefits, adopting nanofertilizers in agriculture requires careful thought of potential difficulties. These include worries about the buildup of nanoparticles in the environment, the possible toxicity of nanomaterials to organisms other than those intended for use, regulatory control, viability from an economic standpoint, and moral ramifications. Interdisciplinary research efforts are essential to fully comprehend the consequences and advantages of nanofertilizers as the field develop, ensuring their appropriate incorporation into contemporary agricultural practices.

Keywords: Agriculture, nano-fertilizer, high-yield, bio-active compounds

Introduction

In comparison to conventional bulk materials, nano-particles (NPs) have unique physico-chemical properties. Their sizes range from 1 to 100 nm. In order to improve crop development and output, nano-fertilizers supply nutrients in nano form (Dimkpa and Bindraban 2016) [10]. The categories of nano-fertilizers can be determined by the requirements of plants. macro nano-fertilizers, micro nano-fertilizers, and nano-particulate fertilizers, into three categories (Chhipa and Joshi 2016) [8]. These particles, which have a diameter of less than 100 nm, can be dispersed as a liquid or a powder (Josef and Katarna 2015) [22]. They give plants the nutrients in a form that they can use, which increases nutrient uptake and increases production.

According to Guru *et al.* (2015) [14], the key characteristics of nano-fertilizers include: (1) appropriate delivery of nutrients for enhancing crop growth through soil and foliar applications; (2) cost-effective and sustainable sources of nutrients for plants; and (3) an important role in reducing environmental pollution.India, a rising and agricultural nation, stresses the need for straightforward, affordable, and effective technologies to improve crop establishment under varied environmental circumstances. Priming of seed is the most straightforward and practical method for synchronizing germination, enhancing emergence, and establishing crops in the field (Ghassemi *et al.* 2017) [13]. However, other sorts of strategies can also be employed to increase crop growth and yield. The review sought to highlight the processes for creating nanoparticles, the function and significance of NPs as nanofertilizers, the effects of NPs on plant and soil quality, and the interactions between NPs and plants.

Manufacturing of nano-fertilizers

The biofabrication of NPs using biological means has attracted a lot of attention due to the growing needs and desire for environmentally safe, efficient, and non-toxic synthesis of nano-material technologies (Abd-El-Hack *et al.* 2021) [3]. The main molecules involved in the creation of NPs in plants and microorganisms are proteins, enzymes, phenolic compounds, pigments, alkaloids, and amines (Hassanin *et al.* 2020) [17]. While chemical methods involve hazardous chemicals that may have an adverse effect on the environment, physical methods are more expensive.

Nano-priming with nano-fertilizers

For obtaining agricultural yields realistically, nano-priming has shown to be more promising than other standard priming strategies (Abbasi *et al.* 2021) [1]. The term "priming" refers to the development of stress tolerance and is used to describe a technique of priming that uses nanoparticles (NPs) smaller than 100 nm (Chandrasekaran *et al.* 2020) [7]. According to reports, nano-priming has the ability to increase seed germination and seedling vigor in a variety of crops (Zhu *et al.* 2019) [36]. Alkaloids, phenylpropanoids, sulfur-compounds, and terpenoids are among the secondary metabolites that are produced when secondary metabolism is induced in plants to counteract harmful environmental stressors. Additionally, they have been used to prevent various diseases and as bioactive chemicals (antimicrobials, antioxidants, and anticancer) (Seca *et al*. 2018) [33].

Nano-fertilizers' function as foliar sprays

The availability of nutrients to plants is significantly hampered by the customary delivery of nutrients to soil. Therefore, the most effective way to address nutritional shortages and improve crop output and quality is to apply nutrients topically. By using less fertilizer on the soil, they also decrease environmental pollution and improve the efficiency with which nutrients are used. Although plant leaves permit gaseous exchange, the cuticle prevents chemicals from penetrating the leaf (Schwab *et al*. 2015) [32].

The use of nano-fertilizers, which have a wide surface area, high absorption capacity, and controlled release to specific sitesa well developed distribution network (Rameshaiah *et al*. 2015) [28]. The relevant research on plant tolerance to abiotic stress, the movement of nano-fertilizers through leaves, and effects on agricultural yield and output should thus be covered. The NPs enter the environment via foliar spray.

Effect of foliar application of nano-fertilizers on plant growth metrics

Because they increase nutrient availability, which improves metabolic processes and encourages meristematic activities, nano-fertilizers play a significant role in physiological and biochemical processes. This leads to stronger apical development and more photosynthetic leaf area. According to studies, black gram plants sprayed with nano-formulations of an NPK and micronutrient mixture grew taller and produced more branches (Marimuthu and Surendran 2015) [24]. Additionally, nano NPK was found to increase wheat leaf growth, which was a result of improved nutrient availability and the formula's ease of penetration. Gas absorption through the stomata. According to Abdel-Aziz *et al*. (2018) [2], peppermint leaves gained 165% more dry weight after receiving foliar applications of nano-fertilizer (nitrogen).

Physiological conditions

An increase in yield was made possible by the foliar application of nano-TiO2, which resulted in significantly greater levels of carotenoids, chlorophyll, and anthocyanins in maize (Morteza *et al*. 2013) [26]. Additionally, it was discovered that using nano-sized TiO2 as a foliar spray has a positive impact on the morphophysiological characteristics of barley, such as the days till anthesis (Janmohammadi *et al*. 2016) [21]. In fact, nTiO2 enhanced the structure of chlorophyll, improved sunlight absorption, facilitated the production of chlorophyll pigments, stimulated RUBISCO enzyme activity, and promoted photosynthesis. In addition to enhancing spinach growth, nano-TiO2 can also increase protein, chlorophyll, and nitrogen metabolism.

Yield: Researchers are currently trying to determine whether nano-fertilizers have the potential to boost agricultural productivity.

According to Abdel-Aziz *et al*. (2018) [2], wheat yield parameters had improved as a result of foliar treatments. Due to increased growth hormone activity and quick metabolic process augmentation, foliar spraying of NPK nano-fertilizers in chickpeas boosted yield and yield components, which tended to promote flowering and grain filling. In addition to lowering fertilizer costs and reducing environmental pollution, the use of nano-fertilizers has a significant impact on cotton yield. Additionally, chickpea development is stimulated by the foliar application of nano iron, nano zinc, and NPK, which increases yield and yield components (Drostkar *et al*. 2016) [11].

The majority of inorganic fertilizers added to the soil are lost and are no longer available for plant uptake. More specifically, 40-70% of nitrogen fertilizer, 80-90% of phosphorus fertilizer, and 50-90% of potassium fertilizer are fixed and/or lost in soils, resulting in a loss of economic value. As a result, soils are being fertilized more.

To make up for the lost fertilizers, which once more influences the soil's nutrient balance. It is possible to wrap fertilizer with nano membranes to enable the slow release of supplements. Nano-fertilizers with gradual releases can be utilized to address the problem of excessive inorganic fertilizer use. These slowly released nano-nutrients may be an option to dissolving inorganic fertilizers due to their sluggish rate of release. The majority of the nutrients that plants need would then be absorbed by the plants (Huiyuan *et al*. 2018) [19]. Furthermore, nanomaterials strengthen fertilizer particles by having a higher surface tension than conventional fertilizers, which improves the effectiveness of regulating nutrient release. Nanomaterials improve the activity of nutrients.

Nanoparticle-coated bioactive compounds

Bioactive compounds are given stability via nano-encapsulations, which protect them from heat, UV, and oxidation. A novel nanotechnology called nano-encapsulation enables the regulated, progressive release of active chemicals from capsules (Saifullah *et al*. 2019) [31]. It resembles microencapsulation in certain ways, but uses nanoscale particles instead of micro.

These bioactive compounds may be delivered in nano-encapsulated materials by a variety of methods, including diffusion, dissolution, or biodegradation.

Nano-micronutrients

Micronutrients like zinc, silica, copper, and iron have been nanoscale produced and employed to enhance plant development. Azospirillumbrasilens and nano Fe were applied topically to maize plants as part of a nano Fe plant growth-promoting rhizobacteria (PGPR) study, which boosted plant growth and yield (Heidari *et al*. 2018) [18]. The phytoremediation of heavy metal enhanced dramatically when PGPR (arbuscular mycorrhizal) inoculated plants with low doses of Fe-NPs, improving the root zone and leaf of young plants (Mokarram *et al*. 2019) [25]. Furthermore, adding nano Zn-Fe oxide and bioagents to salt-stressed wheat plants dramatically enhanced seed development, photosynthesis, and osmolyte content, which includes soluble sugars, proline, and antioxidants (Babaei *et al*. 2017) [5].

NP penetration mechanisms and modes in plants

The hydrophilic head and hydrophobic tails of the phospholipid bilayer that makes up the plasma membrane in plant leaves serve as a barrier to the passage of molecules through it. Three methods were proposed to explain this entrance into plant cells (Behzadi *et al*. 2017) [6]. Due to their small size, NPs can easily traverse the plasma membrane by the first route, which is known as direct diffusion. The passage is linked to a variety of particle characteristics, including size, composition, hydrophobicity, shape, and charge (Auria *et al*. 2019) [4]. In the second pathway, endocytosis, which involves engulfing the cell membrane, NPs are actively carried into the cell. Transmembrane proteins, which control how NPs enter cells, are the third mechanism (Li *et al*. 2020) [23]. However, it is constrained by a few things, including a high level of specificity, a small number of open possibilities, and the size of small pores. The foliar/shoots or roots are the means of transfer from plant cells to tissues. An apoplastic or symplastic method of transport mediates this (Perez-de-Luque 2017) [27]. On the other hand, foliar treatment of NPs in plants causes organ accumulation by phloem translocation (Su *et al*. 2019) [34]. In the outer plasma membrane, apoptosis is transported by means of xylem vessels, extracellular matrix, and neighboring cell walls. It enables NPs to radially move vascular tissue and the root cylinder before ascending to aboveplant's ground components (Sun *et al*. 2014) [35]. Additionally, NPs can enter plants by combining with membrane transporters to create complexes. Nano-materials have the capacity to diffuse to various plant components after entering leaf stomata from the atmosphere. According to Deepa *et al*. (2015) [9], calcium oxide NPs (n-CaO) are seen to be carried by phloem tissue, reduction of abiotic stress Abiotic stresses include those caused by heat, UV radiation, heavy metals, chilling, freezing, and flooding. Among these factors, salt and drought pose a serious threat to crop productivity on a global scale. These abiotic stressors could result in a 50% reduction in productivity. Osmotic and ionic stress brought on by salinity damage membranes and limit enzymatic activity in plants (Hasanuzzaman *et al*. 2013) [16]. Additionally, soil salinity significantly affects plant water availability, nutrient absorption, crop output, and crop quality. Therefore, one of the best ways to reduce these damaging abiotic pressures is to use nanomaterials.

Applications of nanoparticles and their safety in agriculture

Although the use of nano-particles in a wide range of industries, including horticulture, medicines, and agriculture, has great potential, it is still uncertain if these materials constitute a threat to people or the environment. The phrase "nano toxicology" is used to describe both the risky outcomes and a safe method of using nanoscale items. The toxicological features of nanoparticles must be restricted to a single object during a specified time. It is crucial to establish the toxicological data for nano-products in order to identify NPs residues in the environment and/or to be exposed to biological systems. Although there is no conclusive proof that NPs cause human disease, certain studies have hypothesized that they produce biological reactions that result into toxicological issues, including DNA genotoxicity and cell inflammation (Haji *et al*. 2016) [15]. However, these nano products had more pronounced benefits in the improvement. Such as the preservation of the environment, monetary security, and biological sustainability. Before the nano-fertilizer is released onto the market, its effects on the environment and public health must be evaluated and minimized through regulation and product redesign. However, size, dosage, and fabrication materials affect behavior and toxicity. Higher concentrations of nanomaterials employed in plants have negative consequences, whereas lesser levels, when used under the right circumstances, have positive impacts. In contrast to lower quantities (50 mg/L), treatments at high concentrations (>500 mg/L) are phytotoxic (Reddy *et al*. 2016) [30]. Chemically generated NPs can form dangerous substances as byproducts when they interact with other media and have harmful effects (Jaison *et al*. 2018) [20]. The US Food and Drug Administration (FDA) examined the negative effects of NPs and determined that they are neither safe nor dangerous for usage in humans. Prospects for nano-fertilizers in the future. The size of the NP (the smaller the size, the more hazardous as higher specific area), the size of the seed (tiny seeds are more sensitive), the plant species, and the capacity of the seed to adsorb NPs. In order to locate the proper NPs, along with their concentrations and effects on certain crops, new study areas must be expanded. Additionally, study is required to determine how to prevent using herbicides that not only control weeds but also have an adverse effect on crop growth. Can nanoparticles help with this issue? There are numerous environmental problems today, including urbanization and climate change, which have had a significant impact on agriculture. In this condition, lies a scope where the nano technology approaches can be a boon.

Conclusion

The invention of nano-materials is a technological breakthrough in designing material and development. Use of nano technology in agriculture is still in its young stage. However, it has the potential to transform new agricultural systems, especially when it comes to issues of fertilizer application. Nano-fertilizers has exceptional impact on production of crops by reducing costs and emission risks of fertilizers. Nano-fertilizers are more reactive, soluble and increase penetration through cuticle that allows targeted delivery. Crop growth, yield and quality and nutrient use efficiency are improved by application of nano-fertilizers that reduce abiotic stresses and toxicity of heavy metal.

Conflict of Interest: The authors should declare that they do not have any conflict of interest.

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