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The Application of Nanotechnology on Plant Nutrition and Agriculture: A Review

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Abstract

Nanotechnology is one of the most versatile emerging technologies, based on producing and utilizing structures of materials possessing dimensions less than 100 nanometers. It is an interdisciplinary field, and its applications in various sciences and industries are expanding rapidly. Industrial agriculture is among the important experiencing swift advancements in nanotechnology. Industrial sectors have seen swift advancements in nanotechnology, which have led to significant advancements in various branches of this industry. In the field of soil science, nanotechnology is being used for effective plant nutrition management through the use of nanofertilizers, controlling soil-borne diseases with nanopesticides, remediation of salinity and removal of pollutants from soil using nanoparticles and porous nanosorbents, enhancing soil moisture retention capacity through superabsorbent nanomaterials, stabilizing erodible soils using nanosilicates and nanopolymers, and providing various chemical and biosensors for precise soil measurement. Despite all these capabilities, the application of nanotechnology in soil faces challenges such as uncertainty lack of knowledge regarding the environmental risks, complex behavior in heterogeneous soil environments, and expensive synthesis and analytical methods of nanomaterials.

Keywords: Nanotechnology; Plant nutrition; Soil; Agriculture

INTRODUCTION

Nanotechnology encompasses a set of techniques, descriptive processes, and material applications at the nanometer scale. It includes three main branches: nanomaterials, nanotools and nanosensors. A nanometer is equivalent to a very tiny unit of measurement (10-9 meters) and the control of matter inside the range of 1 to 100 nanometers is typically the focus of nanotechnology (Tarafdar et al., 2013).

Nanotechnology has gained significant attention and expanded its application in various fields, including agriculture, in the past decade. Given the mismatch between population growth and food requirements, the importance of nanotechnology as an interdisciplinary and pioneering science becomes evident. It possesses the capability to boost the performance of farming products throughout, cultivation, harvesting, and storage processes, as well as optimize production conditions and food preservation. In fact, approximately 70% of the top 10 priorities for nanotechnology in the world are directly or indirectly related to agricultural sciences (Mukhopadhyay, 2014).

Nanotechnology in food and agriculture

It offers new solutions for improving food security and is capable of revolutionizing diverse aspects of farming. Utilizing nanotechnology is considered a novel approach to enhance food security (Musavi and Rezaei, 2011; Tarafdar and Raliya, 2011).

Nanotechnology has created new and emerging potential applications in the field of agricultural sciences. With this knowledge, it is possible to improve current product management methods. Nanoscience is described, certainly in the America, as innovation and experimentation aimed at

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understanding, manipulating, and measuring materials at the atomic and molecular levels (Reynolds, 2003).

Nanotechnology, as an interdisciplinary field, can have a broad spectrum of uses in the farming industry, leading to significant outcomes such as increased harvest yield, reduced utilization of plant nutrients and insecticides, an extended shelf-life of agricultural products, and perhaps a transformative impact on all stages, inputs, and agricultural tools, aiming for improvement (Pandey, 2020).

Moavini and Khairi (2011) demonstrated a significant impact of titanium dioxide nanoparticles on corn performance. Another experiment, a combination of silica nanoparticles (SiO2) and silver nanoparticles enhanced the functionality of nitrate enzyme in soya beans and enhanced water and nutrient absorption and utilization (Lu et al., 2002).

Furthermore, Mazahernia et al. (2010) viewed significant improvements in various parameters when utilizing iron rust nanoparticles in contrast with conventional iron rust contained in a greenhouse experiment. The application of iron oxide nanoparticles resulted in increased iron concentration in plants, length of spikes, plant height and grain weight per spike, total straw weight, total weight of grain and straw, thousand grain weight and grain weight in wheat. This increase in performance could be attributed to the unique properties of nanoparticles, their higher solubility, lightness and small size, as well as the increased chances of root interaction with nanoparticles compared to conventional iron oxide particles. Additionally, Salehi and Tameshkan (2008) observed that treatment with silver nanoparticles (50 mg/L) led to an increase in germination percentage, length of both stem and root and ultimately improved wheat establishment.

Soil is considered a primary resource for agricultural production, and therefore, preserving its health and fertility is of utmost importance for sustainable food production. It is crucial to maintain the optimal levels of nutrients and moisture in the soil while minimizing the existence of pollutants like heavy metals and toxins. Nanotechnology can significantly contribute to improving this process (Kianian, 2006).

Nanotechnology in fertilizers

Nanotechnology, as an emerging technology, plays a crucial role in optimizing conventional agricultural administrative methods. Through the utilization of nanotechnology in the design and development of nanofertilizers and nano-delivery systems for plant roots, remarkable achievements can be made in increasing the efficiency of chemical fertilizer use. This can lead to significant outcomes such as increased crop yield, reduced production costs, and environmental protection (Nikbakht et al., 2014).

Nitrogen, phosphorus, and potassium are three essential nutrients for plants and are supplied through the utilization of chemical fertilizers. However, the present forms of these fertilizers has the ability to leach 80 to 90% of phosphorus, 50 to 70% of potassium, 40 to 70% of nitrogen into the environment, especially when the particle size is larger than 100 nanometers. These leached nutrients are not absorbable by plants (Askari et al., 2020).

Studies have shown that the application of nano-based fertilizers significantly improves measured traits, including growth-related parameters such as increased shoot and root weight, the number of lateral branches, leaf count, leaf surface area, chlorophyll index, as well as qualitative traits such as protein content, peroxidase enzyme activity and the content of essential nutrients like nitrogen, phosphorus, potassium, calcium, sodium and magnesium in plant aerial parts (Hosseini et al., 2019).

The utilization areas regarding nanotechnology in soil knowledge include various fields, and one of them is plant nutrition. Nanotechnology offers several advantages in this regard, such as precise supply of required plant nutrients, increasing the efficiency of fertilizer utilization and making otherwise inaccessible nutrients available in the rhizosphere. Additionally, it enables the controlled release of fertilizers at the appropriate time for plants, either through root uptake or foliar spraying. This can contribute to reducing the deleterious environmental impact of fertilizer use in agriculture, which has always been a concern (Rai et al., 2015).

Over the past fifty years, advancements in chemical materials technology have brought about a revolution in agricultural production (Vasilevski, 2003).

With the onset of industrial agriculture, which relied on high-yielding crop varieties and the use of chemical fertilizers, agricultural production underwent significant changes and experienced substantial growth. However, the alterations caused in nature due to human interventions in water, soil and air, as a result of using various chemical substances to enhance plant productivity, along with the consumption form of approximately ten times more energy per unit of output compared to the past century, led to the search for new methods in agricultural production (Aladjadjiyan, 2007; Vasilevski, 2003).

The utilization of standard chemical fertilizers has received scrutiny because of their detrimental influences on ecology and food standards. Nanofertilizers, as an alternative to traditional fertilizers, gradually release nutrients in a controlled manner. This prevents groundwater contamination. By employing nanotechnology in the design and production of nanofertilizers, new opportunities have emerged to enhance nutrient uptake efficiency and reduce environmental conservation expenses (Naderi and Abedi, 2012).

Some advantages of using nanofertilizers compared to conventional fertilizers include increased efficiency and quality of food resources due to faster nutrient absorption, reduced loss of fertilizers through leaching and complete nutrient uptake by plants throughout the growing season. Nanofertilizers can release nutrients at an optimal rate, improving soil quality and enhancing plant nutrition. Additionally, it has contributed to the reduction of soil pollution and overall plant health (Naderi and Danesh-Shahreki, 2011).

One of the foremost uses of nanotechnology is the use of nanofertilizers for plant nutrition. By utilizing nanoparticles, particles that are three-dimensionally smaller than 100 nm, controlled-release fertilizers or fertilizers with enhanced properties can be produced. Nanoparticles, due to their unique surfaces, higher density, and increased reactive sites on the particle surface, exhibit high reactivity. These characteristics facilitate the absorption of fertilizers and nanoscale pesticides produced at the nanoscale (Wiswanafhan, 2009).

The nutrition of plants and soil fertility are closely interconnected. The soil should contain an adequate amount of essential nutrients and be able to effectively supply these nutrients to plants. One way to ensure the availability of nutrition in the soil is through the use of appropriate fertilizers. The application of fertilizers not only increases yield production but should enhance the quality of agricultural products. Another important aspect is to avoid environmental pollution caused by fertilizers, as it can pose risks to human, animal, and plant health. Nanotechnology, with its ability to modify and impact the formulation of fertilizers and produce materials with unique properties, can contribute significantly to this field. The use of nanotechnology in fertilizer production can lead to increased amount and level of agricultural commodities while reducing environmental deterioration. The advantages of using these nanofertilizers include:

Formulation Modification: By altering the formulation of fertilizers, it is possible to produce smart fertilizers that release nutrients according to the plant's absorption pattern. This allows for precise nutrient delivery and improves nutrient utilization by plants. Efficient nutrient delivery: nanofertilizers can be produced with nano-sized nutrient particles, enhancing their solubility and distribution in the soil. This results in improved nutrient availability and increased nutrient uptake efficiency by plants.

Reduced Nutrient Loss: The utilization nanofertilizers can diminish nutrient losses through leaching in some cases. The use of nitrogen and phosphate fertilizers can be reduced by up to 50%, leading to a decrease in pollution caused by excessive use of chemical fertilizers.

Enhanced Plant Resistance: Nanofertilizers provide plants with adequate nutrition, increasing their resistance to environmental stress and diseases. This can reduce the need for chemical pesticides and reduce chemical inputs.

Long-Term Soil Interactions: Nanofertilizers can interact with soil microorganisms over an extended period. This can improve soil health and nutrient cycling, promoting sustainable agriculture.

Cost-Effectiveness: The use of nanofertilizers can be economically viable due to reduced fertilizer consumption and increased nutrient use efficiency. By harnessing the potential of nanotechnology in fertilizer production, it is possible to enhance nutrient availability, improve crop yields, reduce environmental pollution and promote sustainable agricultural practices (Kianian, 2006).

Nanotechnology in pesticites

In all countries around the world, synthetic pesticides are primarily produced for pest control in agriculture. The use of these pesticides and their application methods lead to environmental pollution. However, with the help of nanotechnology and the development of new formulations for pesticides, the performance can be enhanced and therefore, the consumption the use of pesticides can be diminished. The utilization of nanosuspensions to increase the efficiency of various types of pesticides, including herbicides, fungicides, insecticides, and rodenticides, has received significant attention (Tsuji, 2001).

The utilization of nano-science in farming is currently in its nascent point, even on a global scale. Nanoscience has contributed to the development and improvement of cost-effective applications of nanotechnology for promoting plant growth. Nanoparticles and nanocapsules serve as effective tools for the controlled distribution of pesticides and fertilizers. As a result, they reduce environmental consequences (Nair et al., 2010).

Pesticides are carried by wind and enter the air, posing risks to human respiratory systems. Nanotechnology addresses the problems associated with pesticides by increasing profitability and reducing the adverse effects, transforming them into highly beneficial products. One of these technologies involves the manufacturing of chemical fertilizers and pesticides employing nanocapsules and nanoparticles. The distinctive properties of nanoparticles, for instance, a large surface region and high reactivity, led to the extensive utilization in various industrial and commercial sectors (Ma et al., 2010). Nanotechnology plays a significant role in improving existing management practices in crop production. Agricultural chemicals, through processes such as leaching, photo degradation, hydrolysis and microbial decomposition, only reach a trivial percentage or fraction to their target site. Therefore, repeated applications are required for effective control, which can result in undesirable consequences like water and soil contamination (Nair et al., 2010).

Nanotechnology in soil fertility

Nanotechnology offers potential solutions to enhance the health and fertility of soil. For instance, nanomaterials can be utilized to deliver nutrients to the flora in a more managed and efficient fashion, ensuring that the required amounts are virtually equal to available. They can also raise the moisture retention capability for the soil and reducing the need for excessive irrigation. Additionally, nanotechnology can be a useful tool in reducing the levels of contaminants in the soil by facilitating their removal or transformation into less harmful forms (Kianian, 2006).

Agricultural practitioners strive to increase production per unit area of agricultural products to satisfy the dietary needs of the multiplying human population. However, improper soil management practices such as excessive tilling, improper tilling practices on the sloppy agricultural lands, unbalanced and excessive use of chemical fertilizers, lack of organic matter incorporation, burning of crop residues and irrigation with polluted water sources have gradually led to the deterioration of soil standard and fertility and transforming them into undesirable and polluted soils (Kianian, 2011).

Indeed, the use of specific soil amendments, such as nano-scale amendments, can perform a crucial part in improving soil conditions and preventing soil degradation. These amendments have the potential to improve soils' physical, chemical and biological conditions and overall soil quality parameters (Nazari, and Tag-Abadi Ebrahimi, 2005). Here are some advantages of nano-scale materials to the soil amendments.

Nanozeolites

Nanozeolites are valuable materials with wide applications in refining processes, as well as in agricultural and environmental engineering. Nanozeolites possess complex structures with extensive interconnecting channels in their crystalline framework. These channels provide ample empty area for cation attraction and substitution. Some reports indicate that the inside facet region of these channels can achieve numerous square of hundred meters per gram of zeolite mineral, yielding zeolites, one of the most effective ion-exchange agents.

The advantages of using nanozeolites in agriculture include:

High Porosity and Water Absorption: Nanozeolites have high porosity, enabling them to absorb and retain water efficiently in the soil. They can improve water-holding capacity, especially in sandy soils, and help evenly distribution of water.

Soil Amendment in Sandy Soils: Nanozeolites can improve the structure of sandy soils, enhancing their water retention capacity and preventing excessive drainage.

Improved Soil Aeration: Nanozeolites can enhance soil aeration by improving soil porosity and preventing compaction, thereby promoting root development and overall plant growth.

Heavy Metal Adsorption and Soil Remediation: Nanozeolites have the ability to adsorb including metals of high density like lead, chromium, nickel, cadmium etc. They could be environmentally and economically feasible tool in the remediation of contaminated soils by trapping and immobilizing these pollutants. Demirkiran et al. (2016) compared adsorption capacities of zeolite-clinoptilolites with oil sorption.

Nutrient Combination and Slow-Release Fertilizer: Nanozeolites can be combined with nutrients and function as slow-release fertilizers. They can retain and gradually release essential nutrients to plants, promoting efficient nutrient uptake and reducing nutrient losses.

It is important to note that the application of nanozeolites in agriculture should be based on careful consideration of specific soil conditions, crop requirements, and potential environmental impacts. Proper dosage and application methods should be followed to ensure optimal results and minimize any adverse effects.

Overall, the utilization of nanozeolites in agriculture holds promise for improving soil properties, water management, nutrient availability and soil remediation, contributing to sustainable agricultural practices and conserving the soils for environmental standpoint (Kianian, 2017).

Nanobiochars

Nanobiochar is among the emerging prospects in nanotechnology for soil amendments. Biochar is considered a renewable source produced from plant biomass or any other organic waste materials, such as residues from textile factories, tanneries, any kind of agricultural biomasses, etc. In this process, the waste materials are transformed into biochar through pyrolysing at a temperature mainly between 300-700oC. This bio-based compound possesses a unique microstructure and high surface area.

Nanobiochar holds multifaceted importance due to its utilization of waste materials, cost-effectiveness and its environmentally friendly nature. The production of biochar from organic residues helps in waste management and contributes to the circular economy. It offers several benefits in agriculture and soil improvement:

Carbon Sequestration: Biochar acts as a carbon sink by sequestering carbon from biomass, reducing greenhouse gas emissions and mitigating climate change.

Soil Amendment: Nanobiochar improves soil fertility, structure, and water-holding capacity. It enhances soil microbial activity, nutrient retention, and nutrient availability for plants. It can be used to amend the acidity problem in soils.

Water Management: Nanobiochar helps in regulating soil moisture levels by increasing water retention capacity and reducing water evaporation. It can contribute to drought mitigation and water conservation efforts.

Nutrient Cycling: Nanobiochar acts as a reservoir for essential nutrients, preventing them from leaching and improving nutrient use efficiency. It promotes nutrient cycling and reduces nutrient losses from agricultural systems.

Soil Microbial Activity: Nanobiochar enables a favorable environment for beneficial soil organisms, mainly microorganisms, and enhancing soil biological activity and promoting plant growth. The application of nanobiochar as a soil conditioner offers a sustainable approach to enhance soil fertility, enhance yield efficiency and contribute to environmental conservation. However, it is important to consider factors such as biochar production methods, feedstock selection and application rates to optimize its benefits and minimize any potential negative impacts on soil health or the environment.

Overall, nanobiochar holds promises as a bio-based soil amendment that utilizes waste materials, offers cost-effectiveness and provides ecological benefits, contributing to the sustainable management of agricultural systems. Therefore, by utilizing nanotechnology in the production of nanobiochar and enhancing its chemical properties, it is possible to harness its features for improving soil quality, increasing crop yield, enhancing the absorption of toxic substances and mitigating climate change. The advantages of using nanobiochar when produced and applied to the soil include (Kianian, 2017).

Carbon Sequestration and Increased Soil Organic Matter: Nanobiochar aids in carbon storage within a specific soil, contributing for the extended element carbon sequestration. It also increases the percentage of soil organic matter, enhancing soil fertility and structure.

Improved Soil Aeration: Nanobiochar enhances soil aeration by improving soil porosity and promoting the movement of soil-air within the profile. This helps in creating a favorable environment for root growth and microbial activity.

Adsorption of Various Pollutants: Nanobiochar has a high surface area and porosity, allowing it to effectively adsorb various organic, inorganic and industrial pollutants. This leads to their reduced release into the environment and helps in conditioning the plant growth.

Enhanced Nutrient and Water Absorption: Nanobiochar has the ability to retain and slowly release nutrients, making them more available to plants. It also increases soil water retention capacity, reduces water stress on plants and enhances water resource utilization.

By enhancing the potential of nanobiochar through nanotechnology, it is possible to address soil degradation, enhance agricultural productivity and mitigate environmental pollution. However, it is crucial to carry out studies towards optimizing the production techniques, determining appropriate application rates and evaluating the protracted effects of nanobiochar on soil healthy and ecosystem sustainability.

Nanohydrogels

Nanohydrogels are hydrophilic polymer networks with high water absorption capacity. Structurally, hydrogels can be classified into anionic, cationic and amphiphilic based on their properties. Most of these materials respond to environmental stimuli such as pH, light, electric fields and more. These unique characteristics have resulted in a broad spectrum of uses for hydrogels, especially in agriculture (Kianian, 2017).

Creating an environment for plant growth that can store nutrients and water for extended periods and gradually release them to plants is one of the main functions of hydrogels, particularly nano-hydrogels. The benefits of using these materials can be summarized as follows:

Water Absorption: Nanohydrogels have nanoscale pores that allow them to absorb water up to several hundred times of their weight. They can retain supplying moisture for an extended period, decreasing the frequency and requirement of irrigation.

Water Retention in Soil: Nanohydrogels enhance water retention capacity in the soil, reducing water consumption for irrigation in the long run. This can be particularly beneficial in arid or drought-prone regions for maximizing benefit of the off-season precipitation.

Nutrient Storage and Gradual Release: Hydrogels have the ability to store nutrients within their structure and gradually release them for plant uptake. This ensures a steady supply of nutrients to the plants and reduces nutrient leaching.

Application in Greenhouses and Apartments: Nanohydrogels can be used in various settings, including greenhouses and city gardening, where water availability and efficient nutrient management are crucial. By utilizing nanohydrogels in agriculture, it is possible to enhance the performance of water utilization upgrade nutrient availability and create a favorable growth environment for plants. However, it is important to consider factors such as the appropriate dosage, compatibility with other agricultural inputs and potential environmental impacts when implementing nano-hydrogels in farming practices.

Nanosensors

Nanosensors are sensors with nanoscale dimensions that measure physical or chemical changes and convert them into electrical signals. Due to their nanoscale size, nanosensors exhibit high precision and sensitivity, allowing them to identify extremely small gas levels within the environment. Nanotechnology sensors are highly fragile, but accurate and sensitive devices able to identify and reacting to biological, physical and chemical triggers.

The small size of nanosensors provides several advantages. First, it allows for a wider specific surface area increasing the interaction between the sensor and the target analyze. This enhances the sensor's sensitivity and responsiveness. Second, the nanoscale dimensions enable nanosensors to be integrated into various systems and devices, including wearable technology, environmental monitoring systems and medical diagnostic tools.

Nanosensors possess a broad spectrum of uses across various fields. In environmental monitoring, they can discern and measure air pollutants, water contaminants, and hazardous substances with high precision. In healthcare, nanosensors can be used for early diagnosis of diseases, drug delivery monitoring, and real-time health monitoring. Additionally, nanosensors find applications in food safety, industrial process monitoring and security systems (Kianian, 2017).

The development of nanosensors opens up new possibilities for advanced sensing technologies, enables more accurate and efficient monitoring and control of our surroundings. However, challenges such as fabrication techniques, integration into complex systems, and ensuring long-term stability and reliability still need to be addressed for widespread adoption of nanosensors in practical applications (Ma et al., 2010). Some applications of various nanosensors in soil include:

Monitoring Soil Temperature: Nanosensors can be used to measure and monitor the temperature of the soil. This information is important for understanding the soil's thermal properties and the impact of it on plant growth and microbial activity.

Controlling and Monitoring Soil Moisture: Soil moisture sensors are utilized for measurement and monitor the humidity level in the soil. This data helps in efficient irrigation management and preventing over-irrigation or deficient-irrigation of plants.

Observing and Monitoring Crop Conditions and Nutrient Levels: Nanosensors can be used to monitor various parameters related to crop growth, such as pH levels, nutrient concentrations and electrical conductivity. This information helps farmers optimize fertilizer application and adjust cultivation practices accordingly. This practice has a specific significance for the hydroponic systems.

Detecting Soil Contamination: Nanosensors can be used to detect and assess soil contamination by pollutants, heavy metals or harmful chemicals. This information is crucial for environmental monitoring and ensuring soil health and quality.

Assessing Plant Growth Hormones: Nanosensors can be employed to measure and monitor the levels of plant growth hormones, like gibberellins and cytokines in the soil. This data aids in understanding plant development, growth patterns, and responses to external stimuli. By utilizing various sensors, farmers and researchers can gain valuable insights into soil conditions, make informed decisions regarding crop management and implement sustainable agricultural practices (Ma et al., 2010).

Nanotechnology in genetic

The utilization of nanotechnology on genetic improvement of plants and animals can enhance the resistance of plants against diseases and other biotic and abiotic stresses. Nanotechnological advancements, particularly in fundamental studies of cellular pathology, will strengthen them and prolong their lifespan in cultivation and consumption locations. It can also accelerate their growth and enable them to thrive in adverse environments such as saline, water-deficient conditions or even colder climates. The possibility of making plants drought-tolerant exists (Zhang et al., 2015).

Nanotechnology in environment

Furthermore, in the waste of water and water industry, the development of nanoscience can bring about significant transformations in water supply and related sectors. The applications of nanoscience for water purification pollution control, optimal utilization of groundwater, and improvement of water structures are among the features that the water and wastewater industry aims to achieve through nanotechnology (Dhawi et al., 2009).

CONCLUSION

In a study titled "Investigating the impact of nanotechnology product production and acceptance on sustainable agriculture from the perspective of agricultural researchers", Mousavi et al. (2009) concluded that the application and position of nanoproducts have a significant and positive relationship with the sustainability of agriculture, as well as the promotion and economic benefits of using nanoproducts. The researcher suggested that nanotechnology has the potential to address pollution, deforestation, hunger, and drought. Musavi and Rezaei (2011) concluded that nanoproducts can provide durable, new, productive, safer, cost-effective, abundant, flexible, environmentally friendly and sustainable consumer goods, as well as contribute to agricultural productivity for larger populations.

Nanotechnology can play a highly effective role in agriculture and natural resources in various areas such as rapid detection of plant diseases, identification and removal of pesticide residues in agricultural products, intelligent delivery of drugs and toxins. It can be used in livestock, aquaculture, water purification, textile industry and genetic engineering of plants and animals (Ditta, 2012).

Currently, there are approximately 200 active nanotechnology research companies worldwide and it is expected that their number will rapidly increase along with the emergence of more advanced and complex applications of this technology (Dhawi et al., 2009). It would be better to use a novel research for the number of nanotechnology companies.

The use of nanotechnology to mitigate the adverse effects of pesticides in agriculture primarily involves substituting hazardous and future pesticides with non-toxic metallic and non-metallic nanoparticles, increasing the efficiency and reducing the dosage of conventional pesticides by combining them with nanoparticles, targeting the effect of pesticides on the intended species and controlling their release through the utilization of nanoparticles, nanosuspensions, nanocoatings, and nanoporous materials. Nanoparticles have been developed to combat various pests such as insecticides, acaricides and pathogenic agents. These nanoscale particles are used to carry pesticides and enhance their efficacy. The active ingredient of pesticides is gradually released, which not only provides economic benefits but also contributes to environmental safety by preventing soil erosion, reducing plant burn and minimizing toxicity to humans (Adhikari, 2013).

The use of nanotechnology has garnered attention in terms of modifying the physical properties and reducing the erodibility of soil through various nanoscale amendments. Modifying soil properties, including water retention capacity, has been reported using nanoscale zeolites, natural nanoporous materials and synthetic nanomaterials. These nanomaterials contribute to enhance the soil-water retention and other physical characteristics of soil (Jatav and De, 2013).

The use of these materials in soil, especially in sandy soils, can increase water holding capacity, reduce irrigation and fertilization costs, revive the biological activity of desert regions and improve the success of irrigation and afforestation programs in dry and semi-arid areas. Additionally, it can help mitigate the effects of drought stress (Karimi et al., 2009).

Metal oxide nanoparticles, porous nanostructures, nanoclays and nanoring bio-polymers are among the materials that have been used to enhance the structure of soil and stabilize loose sand particles to control soil erosion (Hatefi et al., 2016).

In an investigation, silicon, palladium, copper and gold nanoparticles did applied for the earth within two forms: during seed planting in the soil and 15 days prior to seed planting. The findings indicated that when the soil amended with nanoparticles for a duration of 15 days, after which the seeds were sown, a rise in the stem-to-root proportion was observed in relation to the nanoparticles when contrast to the standard. This points out that nanoparticles might lack a straightforward impact influencing plant development but might also act through indirect mechanisms (Shah and Belozerova, 2009).

In an experiment, the application of iron oxide nanoparticles significantly enhanced the "iron levels within" plants in contrast to the standard and the control. This is likely due to the properties of nanoparticles, including higher solubility and increased contact surface with plant roots. However, due to increased competition among plant roots for the absorption of iron, zinc, copper and manganese levels decreased with higher concentrations of nanoparticles. The reduction of zinc, copper, and manganese concentration in plants were lower in the control treatment (Mazahernia et al., 2010).

Nanotechnology has great potential for various applications in soil science, including the utilization for nanofertilizers to plant growth, nanopesticides on pests and plant controlling illness nanosorbents for water and soil purification, nanomaterials for soil water management, nanocoatings for soil protection and nanosensors for accurate measurement of chemical and biological variables in soil. Considering the aspects of risk, toxicity and compatibility with living systems, the use of nanotechnology can lead to desirable outcomes such as enhancing the efficiency of agricultural operations, guaranteeing nutritional safety and promoting conscious and lasting farming practices in emerging nations and area. Chemical fertilizers are commonly used through foliar application on aerial parts of plants or broadcast in the soil for root uptake. However, due to issues like drainage, overflow and vaporization, alone a minor portion within effective nutrient components attain the desired stage, that is significantly "lower than the least required amount" by the vegetation. Consequently, repeated application regarding chemical fertilizers is necessary to achieve effective control over the plant's nutritional status, but this continuous practice can lead to undesirable side effects such as water and soil pollution.

Hence, it enhances to design and advance innovative methods for producing fertilizers that possess features such as regulated discharge of components in reaction to particular "stimuli, enhanced targeted operation, reduced ecological harm, and straightforward and secure" element delivery. This way, the repetitive application of chemical fertilizers can be avoided.

Nanofertilizers can be produced containing low amounts of nutrients at the nanoscale, which enhances their solubility and dispersibility in the soil, leading to improved nutrient absorption efficiency by plants. Reduced nutrient loss: the use of nanofertilizers reduces nutrient loss through leaching. In some cases, the consumption of nitrogen and phosphate fertilizers can be reduced by up to 50%, resulting in a decrease in environmental contamination resulting from the excessive utilization of chemical fertilizers. Due to adequate nutrition and availability of essential elements, plants become more resilient to environmental stress and diseases, leading to a reduced need for chemical pesticides and insecticides.

Nanofertilizers facilitate long-term interactions with soil microorganisms. The reduced fertilizer consumption associated with nanofertilizers provides economic benefits.

In summary, the use of nanofertilizers offers several advantages, including customized formulation, improved nutrient utilization, reduced nutrient loss and enhanced plant resistance. These benefits contribute to more sustainable agricultural practices and environmental protection. Overall, the utilizing nanotechnology in fertilizers production can contribute to the improvement of plant nutrition, soil fertility, and environmental sustainability.

This current the article is an overview paper and the research method used is library study and online exploration in information databases. The data and information of this review have been collected through studying various sources and references.

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AUTHOR CONTRIBUTIONS

The authors contributed equally to this study.

CONFLICTS of INTEREST

The authors declare there is no conflict of interest.

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