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Use of Nanotechnology in Fertilizers

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Abstract: The use of nanotechnology in fertilizers is becoming a popular field of study among researchers worldwide. This matter of fact comes due to the high demand for foods for the world's growing population. This Review article explores nanotechnology's use in the modification of plant nutrient fertilizers over the past few years. This paper also provides information on the various nanofertilizers used for different types of plants such as rice, tea, tomato, fenugreek, date palm, etc. Additionally, this paper also discusses the limitations and drawbacks of the nanofertilizers based on the industrial scale.

Index Terms: nanofertilizer, nanohybrids, nanotechnology, urea.

1 Introduction

The term "Nano" refers to materials with dimensions of 1-100 nm. Nanotechnology covers all technologies related to the Nano-scale. Nanotechnology is used to create a wide variety of nanomaterials for different industries, including medical, agricultural, electronics, and food. Among them, agriculture-based industries need more attention due to the increasing demand for food for the people.

Therefore, fertilizers used in agriculture play an essential role in obtaining high-quality, high yields. As a microscopic nanomaterials structure exhibits unique property variations, those nanomaterials are used to produce improved fertilizers called nanofertilizer. Most of the researchers are giving their priority to make enhanced fertilizers using nanotechnology in different ways. The urgency of such research is now increasing due to the need for sustainable agriculture around the globe.

2 Nutrients in Fertilizers

An adequate supply of some essential minerals is much necessary for the well-growth of a plant. Mineral nutrients required in low concentrations such as iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), boron (B), nickel (Ni), sodium (Na), chlorine (Cl) are called as micronutrients. The minerals required in high concentrations such as nitrogen (N), phosphorous (P), potassium (K) called primary macronutrients, and magnesium (Mg), calcium (Ca), Sulfur (S), silica (Si) are called secondary macronutrients[1],[2]. Among these mineral nutrients, Nitrogen (N) is the pre-eminent element necessary for plants as it is the constituent of chlorophyll, protein, and enzymes [3]. The plants can absorb nitrogen as nitrate and ammonium, but it can be lost through nitrate leaching, de-nitrification, and ammonium volatilization[3].

However, modern industrial agriculture which began after World War II facilitated large-scale production of macronutrients such as N, P, and K. Although these synthetic fertilizers increased the yield of the agricultural industry, on the other hand, it also had some negative impact on the globe. Therefore, researchers needed to find the most cost-effective and environment-friendly fertilizers for agriculture.

3 Nanofertilizers

Nanofertilizer indicates any fertilizer made out from incorporating nanoparticles or made out from using nanotechnology [4]. Nanomaterials can enhance crops' productivity and effectively regulate the supply of nutrients to the plant or target sites. Also, nanomaterials can influence the easy absorption of nutrients from

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roots or leaves while reducing the wastage of fertilizers [5]. Therefore, researchers focus on their studies to either make a fertilizer that can be applied to the soil or spray it to the leaves (Fig. 1) [6].

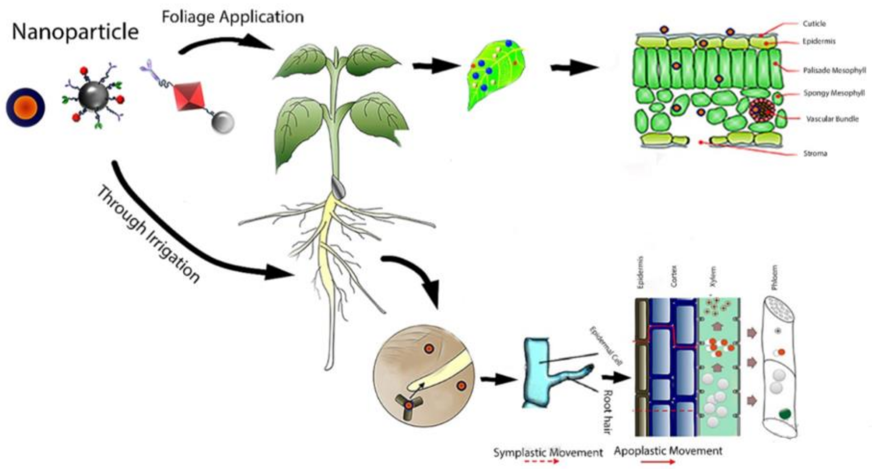

Fig. 1. Uptake mechanisms of nanoparticles in a plant through leaf and roots [6]

There are three classes of nanofertilizers named nanoscale fertilizers, nanoscale additive fertilizers, and nanoscale coating fertilizers[4],[7]. Nanoscale fertilizers are made up of nanoparticles that contain the nutrient. Nano additive fertilizers are fertilizers made from a combination of traditional fertilizers and nanoscale additives. Traditional fertilizers that are coated or loaded with nanoparticles are the fertilizers under the nanoscale coating fertilizer class.

Nano fertilizers can provide nutrients to crops in any of the following ways. One way is the encapsulation of nutrients inside of the nanomaterials such as carbon nanotubes or nonporous materials. Another way is to coat the nutrients with a thin protective polymer film. Besides, nutrients can be delivered as particles or emulsion of nanoscale dimensions[8].

Furthermore, nanofertilizers can be classified based on their actions.

ⅰ) control or slow-release fertilizers, ⅱ) control loss fertilizers, ⅲ) magnetic fertilizers or nanocomposite fertilizers.

Control or slow-release fertilizer means a nutrient-rich fertilizer that delays plant nutrient uptake. Control loss fertilizers are designed to reduce non-point pollution in agriculture [9]. Magnetic fertilizers or nanocomposite fertilizers means a fertilizer that uses a nanodevice to supply a wide range of micro or macronutrients in desirable concentration.

4 NANOTECHNOLOGY IN FERTILIZERS

When it comes to the industrial-scale, urea [$CO(NH_2)_2$] is the most common nitrogen source. Therefore, researchers have focused their studies on urea's use as the main ingredient as the premature decomposition of urea in the soil causes ammonia to evolve before it can be absorbed by the plant [10]. Thus, the researchers used nanotechnology/ nanomaterials to make more effective, efficient fertilizers to overcome conventional fertilizers' throwbacks.

Conventional fertilizers have less bioavailability to plant due to large particle size and less solubility. But because of the nano-sized nutrients in nanofertilizers may improve the solubility and increase the bioavailability. Also, the plants' nutrient uptake efficiency when using conventional fertilizers is lower than that of nanofertilizers [3]. In modern agriculture, nanotechnology is being used to make the fertilizers modernized and more effective instead of applying conventional fertilizers into the field. Commonly, over the last few years, different materials such as clays, silica, hydroxyapatite, graphene, titanium dioxide, calcium carbonate, and also chitosan nanoparticles were used as carrier materials to form nanofertilizers [11-16].

A study on urea-hydroxyapatite nanohybrid for slow release of nitrogen by Kottegoda et al. developed a urea-hydroxyapatite nanohybrid that exhibits a slow release of nitrogen compared to pure urea [11],[17]. They found that the slow release of nitrogen in urea-hydroxyapatite nanohybrid can occur for up to 1 week while the pure urea is expanding within minutes. Furthermore, they introduced this new nanohybrid to rice cultivation and finally concluded that this modified urea-hydroxyapatite nanohybrid could significantly reduce the amount of fertilizer used while maintaining the yield [11]. Another study on Urea-Hydroxyapatite nanohybrid as an efficient nutrient source in Camellia sinensis (tea) by Rajuraj et al. shows the effect of urea-hydroxyapatite nanohybrid fertilizer on the yield and quality of selected tea fields in Sri Lanka [18]. They have observed the impact of nanofertilizer on the tea yield at three climatic zones over three years. They also have concluded that the application of urea-hydroxyapatite nanohybrid could increase nitrogen use efficiency and reduce environmental impact. They have also observed an incense in the quality parameters of tea leaves such as brightness, total polyphenols, and total amino acids.

Furthermore, another important study on urea-silica nanohybrids with potential applications for slow and precis release of nitrogen by Madhavi et al. have synthesized urea-silica nanohybrids with a high urea loading of 36% (w/w) using a modified in-situ sol-gel method [15],[19]. They have used silica nanoparticles as the carrier material for urea, by selecting silica as the carrier material gives another advantage to the plant as a micronutrient. They have observed that the developed nanohybrid releases urea slowly for more than ten days.

Kottegoda et al. have studied about two new plant nutrient nanocomposites based on urea coated hydroxyapatite in 2016 [17]. In there, they have synthesized two plant nutrient nanocomposite based on urea and potassium. They have used urea coated hydroxyapatite, potassium encapsulated montmorillonite nanoclay, and potassium encapsulated wood chips. In there, they have encapsulated potassium into the cavities present in the stems of *Gliricidiasepium*. After the experiment, they concluded that these two new plant nutrient nanocomposites could provide a good platform for developing efficient fertilizers in the future [17]. Another critical study is on preparing nanofertilizer blend from banana peels by Hussein et al. in 2019 [20]. In there, they have obtained nanofertilizer from banana peels as it contains essential nutrients. They have then applied the extracted nanofertilizer from banana peels in the agriculture of two crops (tomato and fenugreek). Extracted nanofertilizer contained constituent spherical nanostructure of about 40 nm in particle size. With the addition of new fertilizer, the germination percentages of both crops were increased in the first planting week.

A study on foliar nanofertilizer enhances fruit growth, maturity and biochemical responses of date palm by Hussein et al. shows the effect of foliar nanofertilizer on the growth and fruit ripening rate of date palm [5]. Their experimentation results show improved growth and increased production after adding nanofertilizer with a portion of conventional fertilizer due to the increment of metabolic activity in date palm fruits. Dasuni et al.

studied urea-modified calcium carbonate nanohybrids as a next-generation fertilizer in 2019 [21]. In there, they have attempted to synthesis a novel urea-modified calcium carbonate nanohybrid. They have used the in-situ rapid carbonation method to develop the urea modified calcium carbonate nanohybrids. In the end, they have observed a controlled release of nitrogen with the modification of calcium carbonate nanoparticles when compared to the conventional method. Through that, they were able to introduce a new controlled-release fertilizer system.

Another important study on the effect of citric acid surface modification on the solubility of hydroxyapatite nanoparticles done by Ranuri et al. in 2018 shows a developed P nutrient supply system for plants compared to common P nutrient supply methods [22],[23]. They have modified the hydroxyapatite nanoparticles with citric acid using both in-situ and ex-situ modification methods. The modified nanofertilizer was used to cultivate *Zea Mays* (corn) under the recommendations of the department of agriculture in Sri Lanka to check the bioavailability. As a result, they have observed a significant improvement in plant growth and crop productivity with the addition of citric acid-modified hydroxyapatite nanoparticles [20].

Apart from that, the most interesting use of nanotechnology in fertilizers is the production of smart fertilizer in the modern agricultural world. Although nitrogen is the primarily required macronutrient for the plant, the amount of nitrogen required may differ from crop to crop due to specific environmental and plant conditions. Therefore, researchers are focusing on making fertilizers with nanobiosensors. Nano-biosensors can detect single or multiple analytic concentrations within parts per trillion and limits the analyzed matrix based on nanoformulation [6]. Nano-biosensors can be used to improve yields by managing not only water and pesticides but also fertilizers. Using nanobiosensors with fertilizers can reduce the amount of fertilizer lost during cultivation.

5 LIMITATIONS OF NANOFERTILIZERS

Even though nanotechnology has provided many benefits to fertilizers' production, there are some limitations and drawbacks that can also be identified. Production availability and practical issues are the main limitations of nanofertilizers when it comes to a large scale. Also, the higher cost of production and lack of standardization can consider as major limitations [3]. Since this technology is new to the world, the risk of nanoparticles application in crops has not been assessed [1]. This is because nanoparticles can be entering the human /animal body through oral, respiratory, or intradermal routes. Therefore, risk assessment studies also have to be followed by the production of fertilizers on the nanoscale.

6 CONCLUSION

Due to the growing global food demand trend, it is necessary to get high yields of good quality crops with minimal waste. In there, fertilizers play a vital role in the world today. Many researchers are currently researching this issue, and nanotechnology is focusing more on it. Considering nanotechnology in fertilizers, some researchers have already shown that the activation of nanotechnology for the production of fertilizers has yielded better results than conventional fertilizers. Nanofertilizers can increase the yield of crops, the efficiency of nutrient uptake, and reduce the loss of nutrients during cultivation. Although nanotechnology has provided many benefits to the production of fertilizers, some limitations also can be identified.

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