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Nano-fertilizers for Sustainable Agriculture

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Abstract

Today's farming community across the world is facing a wide spectrum of challenges in crop production systems. The important ones are climate change, food and nutritional security, depletion of soil fertility, decline in response to applied fertilizers, decline in water table depth, increased disease and pest incidence in crops and socio-economic issues of the farmers. So, it would be difficult to produce enough food to feed the ever increasing population, which is expected to cross nine billion by 2050. Nanotechnology is having the huge potential to address these challenges with its applications in the field of agriculture. Traditional fertilizers are not only costly for the farmers, but also harmful to human beings and to the environment. This has led to the search for Environment friendly fertilizers, particularly those with high nutrient-use efficiency. The benefits of Nano-fertilizers or Nano-materials are unquestionably opening new approaches towards precision farming and sustainable agriculture.

1. Introduction

Chemical fertilizers provide nutrients required for optimal growth and development of plants, however current production practices cannot fulfill the growing demand of food without reliance on the extensive use of fertilizers. Furthermore, intensive application of conventional fertilizers over extended periods has caused serious environmental problems worldwide including ground water pollution, eutrophication (algal growth on the surface of water bodies due to nutrients enriched water, which hampers oxygen supply to fish), soil quality degradation, and air pollution. On the other hand excess application of chemical fertilizers reduces profit margins for growers because of their higher cost. Low nutrient use efficiencies are typically the result of high release rates of conventional fertilizers after their application in the field resulting in less uptake by crops and heavy losses in the form of leaching, runoff and denitrification. Using the more efficient mineral fertilizers is a necessary approach to fulfill the increase in food production required to feed the increasing population and support economic

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development. As such, there is a great interest towards the development of new innovative fertilizer sources in order to increase the fertilizer use efficiency. Several strategies have been proposed to increase fertilizer use efficiency, such as the use of precision fertilization, split or localized application, fertigation, and the use of Nano-fertilizers.

2. Nano-fertilizers

The term "Nano" means one billionth part of a meter and is adapted from the Greek word meaning "dwarf." Particles with at least one dimension less than 100 nm are considered as "nanoparticles" (Thakkar et al. 2010). There are various types of Nano-materials such as single or multiwalled nanotubes, magnetized iron nanoparticles, copper (Cu), aluminum (Al), silver (Ag), gold (Au), zinc (Zn) and zinc oxide (ZnO), silica (Si), cerium oxide (Ce2O3), and titanium dioxide (TiO2). Important properties of nanoparticles are they have high surface area to volume ratio which makes them suitable for developing need based products with higher efficiency. In this context, application of nanotechnology for the development of new types of fertilizers is regarded as one of the potentially promising option for significantly boosting global agricultural production. A correct application of Nano-fertilizers can feed plants gradually in a controlled manner along with the benefits of increasing the fertilizer use efficiency and reducing the environmental hazards. Nano-fertilizers have the potential to increase crop productivity by enhancing seed germination, seedling growth, photosynthesis rate, nitrogen metabolism, and protein and carbohydrate synthesis, aside from improving stress tolerance. Among other advantages, Nano-fertilizers can be applied in a comparatively smaller amount, ultimately reducing the transport expenditures and increasing ease of application.

3. Production of Nano-fertilizers

A Nano-fertilizer is any product that is made with nanoparticles or uses nanotechnology to improve nutrient use efficiency.

Three classes of Nano-fertilizers

1. Nano-scale fertilizer (nanoparticles which contain nutrients)

2. Nano-scale additives (traditional fertilizers with Nano-scale additives)

3. Nano-scale coating (traditional fertilizers coated or loaded with nanoparticles).

Examples of potential Nano-fertilizer designs (Manjunatha et al., 2016)

The nano-fertilizers are synthesized by fortifying nutrients singly or in combinations onto the adsorbents with nano-dimension. Both physical (top-down) and chemical (bottom-up) approaches (Figure 1) are used to produce nanomaterials, and the targeted nutrients are loaded as it is for cationic nutrients (NH^{4+}, K^{+}, Ca^{2+}, Mg^{2+}) and after surface modification for anionic nutrients

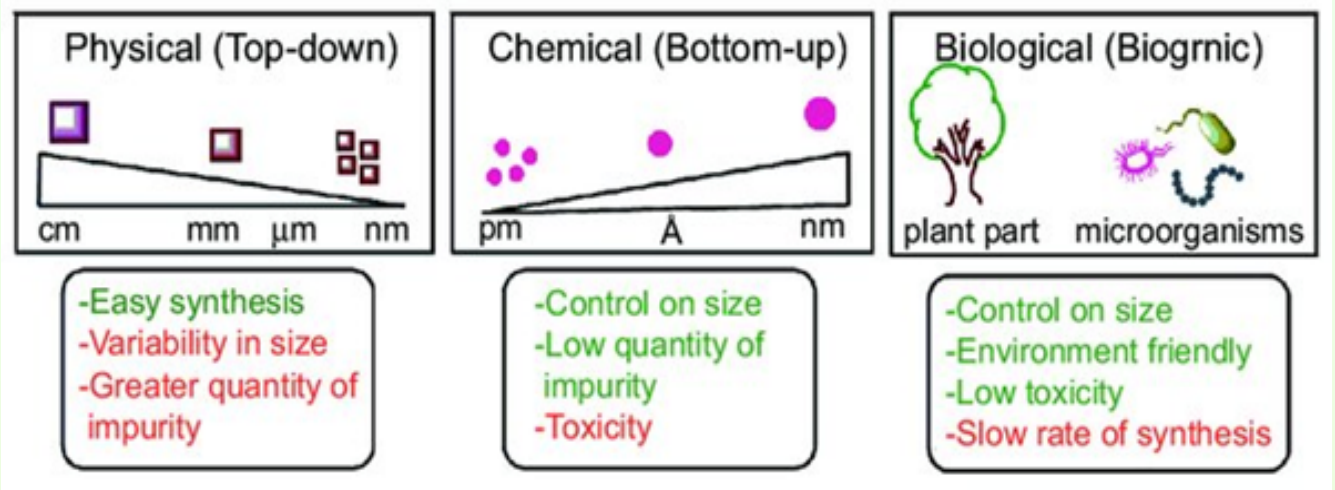

Figure 1: Representation of methods for the production of nanofertilizers: physical (top-down), chemical (bottom-up), and biological approaches and advantages and limitations represented in the lower text box with green and red color, respectively

(NO_3^-, PO_4^{2-}, SO_4^{2-}).

Second approach for production of nano-fertilizers is encapsulation of fertilizers within a nanoparticle is one of these new facilities which are done in three ways

a) The nutrient can be encapsulated inside nano-porous materials,

b) Coated with a thin polymer film, or

c) Delivered as particles or emulsions of nano-scales dimensions.

4. Conventional Fertilizers Versus Nano-fertilizers

Important benefits of Nano-fertilizers over conventional chemical fertilizers rely on their nutrient delivery system. They regulate the availability of nutrients in crops through slow/control release mechanisms. Such a slow delivery of nutrients is associated with the covering or cementing of nutrients with Nano-materials. By taking advantage of this slow nutrient delivery, growers can increase their crop growth because of consistently long-term delivery of nutrients to plants. For example, nutrients can be released over 40–50 days in a slow release fashion rather than the 4–10 days by the conventional fertilizers. In conventional nutrient management systems, half of the applied fertilizer is lost in leaching or becomes unavailable for the plant because of excessive availability hindering the roots to uptake or sometimes causing toxic effects on the plant. In conventional nutrient management system, it is very difficult to control the micronutrient delivery to a specific crop, but Nano-fertilizers provide the opportunity to the growers for supplying adequate amounts of nutrients. Furthermore surface coatings of Nano-materials on fertilizer particles hold the material more strongly due to higher surface tension than the conventional surfaces and thus help in controlled release (Brady and Weil, 1999). These attributes of nanoparticles are due to their high surface area to volume ratio, high solubility, and specific targeting due to small size, high mobility, and low toxicity (Sasson et al., 2007).

5. Uses of Nano-fertilizers in Agriculture

Nano-fertilizer applications in agriculture may serve as an opportunity to achieve sustainability towards global food production. There is a tremendous food production pressure on the sector as nutritional deficiencies in human populations are mainly because of using less nutritious food and a low dietary intake of fruits and vegetables. Nano-fertilizers are eco-friendly and increases nutrient use efficiency (NUE) more than three times and 80-90 times less requirement than chemical fertilizers, 10 times more stress tolerant by the crops, 30% more nutrient mobilization by the plants and 17-54% improvement in the crop yield. Nano-fertilizers play a vital role in the improvement of yield in comparision to conventional fertilizers (Table 1) in the wide array of crops (Zulfiqar et al., 2019).

Table 1: Impact of nano-fertilizers on productivity of different crops

Nanofertilizers	Crop	Yield increment (%)
Nano-encapsulated phosphorus	Maize	10.9
Nanoparticles of ZnO	Chickpea	14.9
Nanofertilizer+urea	Wheat	6.5
Nanofertilizer+urea	Rice	10.2

Nano-fertilizers reduce the need for transportation and application costs. Advantage of using small quantities is that the soil does not get loaded with salts that usually are prone to over-application using conventional fertilizers on a short- or long-term basis. Another advantage for using Nano-fertilizers is that they can be synthesized according to the nutrient requirements of intended crops. In this regard, biosensors can be attached to a new innovative fertilizer that controls the delivery of the nutrients according to soil nutrient status, growth period of a crop or environmental conditions. Nano-fertilizers increase the bioavailability of nutrients through their high specific surface area, miniature size and high reactivity. On the other hand, by providing balanced nutrition, Nano-fertilizers enable the plant to combat various biotic and abiotic stresses, with overall clear advantages. However, the extensive use of Nano-fertilizers in agriculture may have some important limitations, which must also be considered.

6. Limitations of Nano-fertilizers

Recent progress is undoubtedly witnessing the successful use of some Nano-fertilizers for achieving enhanced crop productivity. However, the deliberate introduction of this technology in agricultural activities could result in many unintended non-reversible outcomes. In this scenario,

new environmental and unintended health safety issues can limit the use of this technology in agriculture. Importantly, Nano-materials are very reactive because of their minute size with enhanced surface area. Reactivity and variability of these materials are also a concern. This raises safety concerns for farm workers who may become exposed to xenobiotics during their application. These include not only those exposed to Nano-fertilizer manufacturing but also Nano-fertilizer application in the field. Hence, it is crucial to consider the advantages of Nano-fertilizers, but also their limitations before market implementation.

7. Conclusion

Nano-fertilizers have potential to increase crop productivity through slow or controlled delivery of nutrients required for plant growth, due to their small size and target specificity, they increase the use efficiency of the fertilizer and helps in reducing negative impact of fertilizers on environment. The availability and production process involved in nano-fertilizers is very complex because of lack of technologies and expertise in the field. Future studies must be focused on generating comprehensive knowledge on nanotechnology in order to achieve sustainable agriculture.

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