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NANOFERTILIZERS: A SMART APPROACH TO SUSTAINABLE AGRICULTURE

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Abstract:-

As the population increases day by day, there is a huge demand of food supply. Also, it is very much important that to adopt a farming system more sustainability for better production without the use inorganic or other mineral fertilizer. Therefore, growing interest in the use of nanofertilizer is a major approach to improve crop growth, yield and quality with increase nutrient use efficiency, reduce wastage of fertilizers. Nano-fertilizers are mostly sub-microscopic sizes, also have a large surface area to volume ratio, nutrient encapsulation, and greater mobility therefor they may increase plant nutrient along with crop yield. Such properties Nano-fertilizers are regarded as a good deliverable 'smart system of nutrients.'

Keywords: Nanofertilizer, conventional fertilizer, plant nutrients

Introduction:

The demand for agriculture and agricultural goods has increased to an unprecedented level due to the growing population and shrinking amount of arable land. In order to meet the food demands and minimize poverty, there is a decrease in the quality and quantity of resources into the farming system. Besides, agriculture is facing several problems regarding water scarcity, land shrinkage, climate change, decrease in crop productivity, also environmental issues like soil erosion, fertilizer and pesticide accumulation leading to toxicity and nonetheless labor scarcity.

More specifically, without fertilizers, large-scale food production would remain out of reach for the majority of people because fertilizers are an essential component of commercial farming. There are lower crop yields resulting from various factors such as leaching, degradation, insolubility and leading to insufficient availability of the same for crops (Food and Agriculture Organization of the United Nations, n.d.; Olad *et al.*, 2018; Seleiman *et al.*, 2020). To improve agricultural inputs and cultivation techniques, a number of innovative techniques and technologies have emerged in recent years. Nanotechnology is one of them.

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It has been used in different fields of agriculture.

Nanotechnology methods can improve nutrient uptake of plants, help in targeted delivery of chemicals inside plants. Sizes of nanomaterials range from 1-100 nm and they have properties that set them apart from their corresponding bulk materials. These are gaining importance because of characteristics like electrical conductance, magnetism, chemical reactivity, surface reactions, optical effects and physical strength (Prasad *et al*., 2017; Rai & Ingle, 2012).

nutrients, conservation of natural resources and reducing the demand of traditional fertilizers thus increasing food productivity and quality. Nanofertilizers have the potential to overcome problems like overdosing as in traditional fertilizers as well as wastage during fertilizer application (Toksha *et al*., 2021).

Synthesis of nanofertlizers

There are two approaches of nanofertilizer preparation. Those are top-down and bottom-up approaches. In top-down (physical) approach, bulk materials are converted into nanoscale forms through

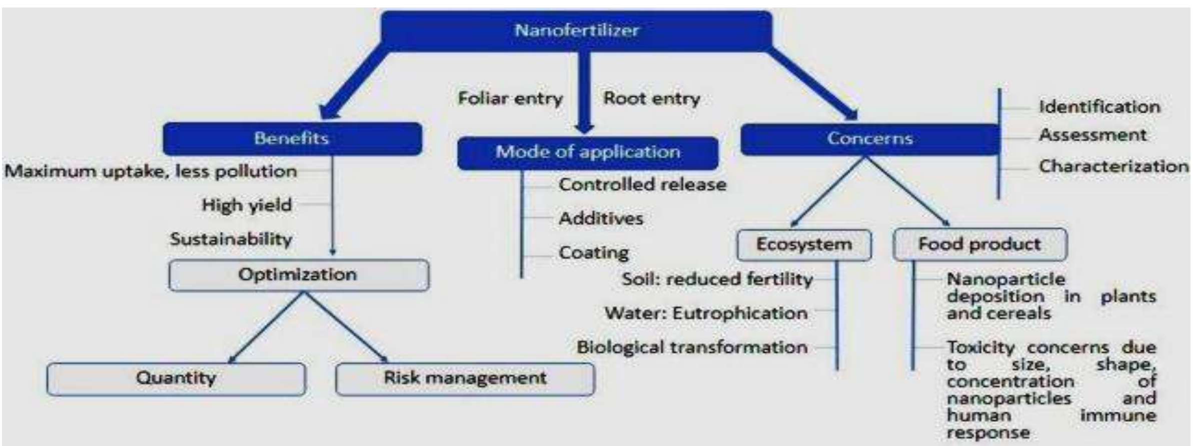

Figure 1: Different aspects of nanofertilizer application (Toksha et al., 2021)

Nanofertilizers

Nanofertilizers are nanoparticles containing essential and beneficial nutrients for plants that are applied through various pathways to provide the required nutrients by plants. These facilitate several functions like delivery of nutrients directly to the plants, improve soil biological health, microbial diversity, immobilization of local soil

processes like milling, grinding, etching, etc. while in bottom-up (chemical) approaches, self-assembly and self-organization of materials take place to produce nanoscale materials(Toksha *et al*., 2021). In physical methods involve methods like gas condensation, attrition ball mill, low energy tumbling mill, high energy ball mill, et. that are explored by many researchers for the

Figure 2: *Advantages of nanofertilizers* (Babu *et al*., 2022)

production of fertilizers, pesticides, herbicides, etc. Easier synthesis, lesser time requirement and the benefit of large-scale production makes physical methods more approachable and popular. Oxides of elements like titanium, chromium, cobalt, aluminum, etc. are used as nanofertilizers created using physical approaches (Toksha *et al*., 2021).

Chemical synthesis involves buildup of nanomaterials from the atomic level through chemical reactions. Some of the common synthesis methods of this category are sol-gel technique, chemical vapor deposition, chemical precipitation, etc. This type of synthesis approach facilitates control over size distribution, reduction in impurities, lower temperature methods, etc (Toksha *et al*., 2021). In green synthesis uses of algae, fungi, bacteria, and plant extracts, which produces a variety of non-hazardous, environmentally benign, and biocompatible nanoparticles.

Different plant parts like seeds, flowers, leaves, stem, etc. are used to prepare nanoparticles for providing nutrients to plants. These extracts contain various phytochemicals and some of these acts as natural stabilizing agents and/or reducing agents in the production process itself. (Singh *et al*., 2024).

Characterization of nanofertilizers

In order to define the specifics of the nanomaterials prepared using the above-mentioned techniques and to get clear information about their surface and sub-surface morphologies as well as their characteristics, several techniques are put to task. These include techniques such as Scanning Electron Microscopy (SEM), Tunneling Electron Microscopy (TEM), Electron Dispersive X-ray Spectroscopy (EDS), UV-visible Spectroscopy, Raman Spectroscopy, Fourier Transform Infrared Spectroscopy (FT-IR), X-ray Diffraction

(XRD), Thermogravimetric Analysis (TGA), Dynamic Light Scattering (DLS), etc. These techniques are very important to get information about the surface structure, bond energies, functional groups present, particle size, thermal reactivity, elemental composition and many more data about the nanoparticles, which ultimately confirms the formation of the desired nanofertilizer (Fathy *et al*., 2024; Mitra *et al*., 2023)

Uptake mechanisms of nanofertilizers in plants

The plant cell wall, with whole diameters ranging from 5 to 20 nm, functions as a barrier to external stimuli, including nanoparticles (NPs). NPs that are smaller than these holes can penetrate through the plasma membrane. Interaction with designed NPs may expand or form new pores, which improves uptake. Endocytosis, transport proteins, and ion channels are all possible mechanisms for internalization.

Foliar application

Trichomes, stomata, stigma, and hydathodes absorb NPs, which are subsequently transferred via the phloem and xylem systems. There are two primary transport pathways-Apoplastic, where nanoparticles travel through cell walls and intercellular gaps, with size exclusion limits (SELs) of 5-20 nm and symplastic, through plasmodesmata with SELs ranging from 3 to 50 nm.

Root application

Nanoparticles (NPs) enter the root epidermis, travel through the endodermis, and reach the xylem, which carries them to the plant's aerial parts. NPs sized between 3 and 8 nm can penetrate through cell wall pores. They can also infiltrate the root tip meristem or lateral root development sites if the Casparian strip has been damaged. To reach the root's epidermal layers, NPs must pass through cell walls and plasma membranes before entering vascular tissues (xylem). While cell wall pores are normally 3 to 8 nm in size, making them too tiny for NP penetration, NPs have been found to cause the creation of bigger holes, allowing for better internalization (Wang *et al*., 2023).

Types of nanofertilizers

Nanofertilizers can be categories as - action based, nutrient based and consistency based.

- ❖ Action based nanofertilizers include controlled release (carbon based like graphene, chitosa-based for delivering NPK, clay-based, layer double hydroxides like [Mg-Al]-LDH for phosphate fertilization, nanocapsule based like zinc oxide nanoparticles, starch based like Cu-Zn carrying carbon nanofibers, etc.), targeted delivery (nanoaptameters that can deliver nutrients by attaching them to nanoparticles like gold nanoparticles or liposome), plant growth stimulating (carbon nanotubes) and water and nutrient loss controlling (nanobeads such as N-Flex from Limagrain Europe, nanoemulsions consisting of nanosized droplets of nutrients).

- Nutrient based nanofertilizers include inorganic (N based, S based, K based, etc.), organic (liposomes, micelles, dendrimers, etc. formed from organic materials like plant parts), hybrid and nutrient-loaded ones (nanoporous zeolite fertilizers).
- Lastly, consistency based nanofertilizers include surface-coated, synthetic polymer coated, biological product coated and nanocarrier based ones (Yadav *et al*., 2023).

Applications of nanofertilizers and their effects on crop productivity

Plants require macro and micronutrients as well as beneficial elements to sustain their growth and development. Most of the nutrients essential for plant growth are present in soil but their availability to plants is very limited due to factors like leaching, land degradation, water logging and so on. This requires the external application of fertilizers (most inevitably, the macronutrients like nitrogen, phosphorus, potassium, etc.) through soil and foliar applications or sometimes seed priming. They can be applied also with irrigation water. Nanomaterials act as superior forms of fertilizers as they can overcome these issues faced by conventional fertilizers. Nanotechnology in fertilizer synthesis involves the encapsulation of nutrients in nanomaterial structures and complexes, coating of nutrients with nanomaterial layer, nutrient and nanomaterial complexes, emulsions or nanoparticles.

Nanofertilizers, especially carbon-based and metallic ones have proven to improve the growth and development of crops (Nair *et al.*, 2010). These fertilizers facilitate assimilation, translocation, delivery and storage of compounds essential for plants. Many studies have reported positive impacts in morphological as well as physiological aspects of crops kike spinach, soybean, etc (Gao *et al.*, 2006). Nano fertilizers also boost germination rates by improving water absorption, root and shoot length, vegetative biomass, and photosynthetic rate, which increases light retention and diffusion in the plant. Water pollution can be avoided by using nano fertilizers because nutrients are released into the soil in a regulated manner, preventing nutrient loss and making nutrients easily available to plants.

Conclusion and Future prospects

Recently nanotechnology has received a particular attention also adopted in many countries because it has the potential to significantly improve sustainable agriculture by developing novel nano-based fertilizers, pesticide and fungicides. These technologies can improve agricultural security while also addressing environmental issues. Despite the controlled nutrition release by physical and chemical techniques, the biological consequence of these processes is unknown. More study is needed to optimize nutrient delivery, understand nutrient interactions at the physiological and molecular levels, and examine the biosafety of nanofertilizers.

Although nanotechnology has significant advantages for agriculture. To reach its full potential, equitable support from both the public and commercial sectors is required. Prioritizing research and development, particularly on the long-term consequences of nanomaterials in the environment, is critical for moving the agricultural industry forward and helping farmers.

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