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Review Article

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Next Generation Micronutrient Nanofertilizers for Sustainable Crop Nutrition: A Review

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Abstract

Today's agricultural practices have caused harm to formerly healthy soil, brutally reducing essential minerals while disrupting the delicate balance of the neighbouring ecology. The excessive use of these conventional fertilizers degrades soil quality, pollutes the environment, and damages agronomic ecosystems. Nanofertilizers (NFs) are critical determining elements in agriculture for improving yield, growth, and providing improved nutrient utilization efficiency (UE), lower cultivation expenses, and reduced fertilizer waste. These items may be effective in addressing contemporary agricultural issues. Globally, micronutrients are encapsulated using various materials to increase their release, so that plants can have optimal nutrient availability, however plants are not obtaining the full advantage. This review identifies technological gaps that frequently exist in crop efficiency and micronutrient release, it proposes an innovative foresight involving technical and scientific theories, with a greater emphasis on enhancing the micronutrient use efficiency of critical elements such as Mn, Ni, Mo, Fe, B, Zn, and Cu by crops. Additional research is needed to truly comprehend their lasting impact on crop output and soil wellness.

Keywords

Micronutrients, Nanofertilizers, Zinc oxide nanofertilizers, Iron oxide nanofertilizers, Micronutrients

Introduction

The development of reliable and environmentally safer procedures for nanomaterials production is critical for overcoming limitations in nanotechnology such as high cost, toxicity, and time consumption. Nanotechnology is being used in a variety of essential human endeavours, pharmaceuticals, water treatment, cosmetics, medicine, electronics, environmental remediation, and agriculture [1]. The most crucial components needed by plants, such as K, P, N, and have all had lower nutrient UEs throughout the previous four decades: 30 - 35%, 18 - 20%, and 35 - 40%, respectively [2]. Growers are forced to add more nutrients than necessary due to inefficiencies in their distribution to and utilization by plants, which cause emissions, leaching, and runoff that can contaminate the environment. According to several studies, fertilizers using nanotechnology could supply nutrients to plants more effectively [3]. Agriculture plays a critical role in sustaining the world's ever-growing population and driving the burgeoning economy. Engineered nanomaterials have been found to improve food safety and plant productivity as nanofertilizers through foliar and soil treatments [4]. The intended application of NFs aims to improve nutrient usage efficiency, lower nutrient immobilization, and lower agricultural waste as well as nutrient runoff through leaching and volatilization [5]. Along with macronutrients, the importance of micronutrients in global agriculture and human health is well understood. Billions of people are thought to be suffering from micronutrient deficiencies around the world. Some of the micronutrients that are limiting variables in terms of yield that are involved in stumpy food nutrition are Cu, Mn, Zn, Ni, Mo, and Fe. Recent research has demonstrated the advantages of organically produced micronutrient NFs over conventionally synthesized nanoparticles (NPs), emphasizing their favourable effect on the growth of plants [6]. Although nanotechnology can increase the bioavailability of micronutrients for plants, how NFs are applied also affects how effectively they fertilize. To increase the strength and health of the soil, nano-micronutrient formulations are mostly sprayed on plants or given to the soil for root ingestion. The micronutrient UE, a critical concept that must be described here, is the organic matter production per fertilizer or nutrient intake [7]. Since different nutrients are needed by plants in varying amounts. NFs, which are categorized into three types: Nanoparticulate, macronutrient, and micronutrient NFs, have emerged as potential plant development and proliferation approaches [3]. The current review paper focuses on the micronutrient NFs and their applications.

Methodology

A comprehensive evaluation of applicable literature was done to identify publications related to the study's purpose. Keywords such as "nanofertilizers", "micronutrients", "micronutrients nanofertilizers", "zinc oxide nanofertilizers", and "iron oxide nanofertilizers" were used to find out the data. More than 100 research and review articles that had been published in reputable journals were examined, and the best ones were chosen to serve as a summary of the data. For this report, literature reviews were looked up using a variety of databases, including Research Gate, Web of Science, Google Scholar, Scopus, and records from reference books.

Types of NFs

Macronutrients, micronutrient, carbon, and polymer-based NFs are some examples of the various types of NFs that can be produced depending on the nutrient and carrier used (Figure 1) [8].

The three main macronutrients are K, P, and N. Nitrogen plays a crucial role in energy metabolism and protein synthesis, making it important for plant development. Plants require far fewer micronutrients than macronutrients for growth. The elements Zn, B, Cl, Mo, Cu, Mn, and Fe are present in micronutrients [9]. Polymers like chitosan, alginate, albumin, and others can carry NPs. In-depth research is being done on the use of polymers, like the ones indicated above, in the transport of NPs to plants. Living tissues contain very minute levels of minerals or trace metals. While some of these are necessary for good nutrition, others are not. For instance, there are fourteen trace elements altogether. Cd, As, Pb, Cr, Co, and V are among the metals that make up the elements Rb, Sr, Fe, Mo, Se, Mn, Cu, and Zn [10].

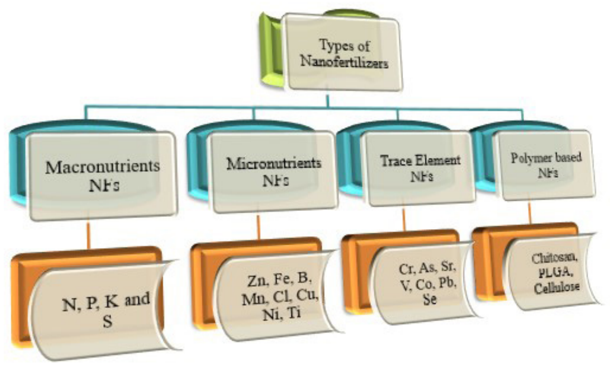

Figure 1: Represents the various types of NFs.

Commonly Used Micronutrient NFs

as micronutrient-based NFs use NPs to supply vital micronutrients micronutrient-based NFs use NPs to provide vital micronutrients to plants than traditional fertilizers. The various examples of micronutrients are Zn, Fe, Mo, B, Cu, Ni, and Mn (Figure 2) are essential for general health, plant growth, and development.

The micronutrients Ni, Zn, Fe, Mo, Mn, B, and Cu are those that crop producers and practicing agronomists can reasonably influence. Plants require a varied range of concentrations for each micronutrient (Table 1). These essential nutrients may become more accessible because of nanoscale nutrient forms, which can also increase nutritional quality, plant metabolic process, plant growth and development [4]. Plants can benefit from micronutrient NFs in a variety of ways, including higher nutrient uptake, and greater production as will be covered below:

Role of Zn in plants

Zn, which is ranked as the 3rd most prevalent metal after Mn, and Fe nutrients. Numerous plant metabolic, biochemical, and physiological processes are mediated by Zn [12, 13]. Furthermore, Zn is required for several enzymes involved in nitrogen metabolism, protein synthesis, and energy transmission [14]. Zn deficiency can result in slowed plant growth, which can lead to fewer tillers, a reduced incidence of chlorosis, and

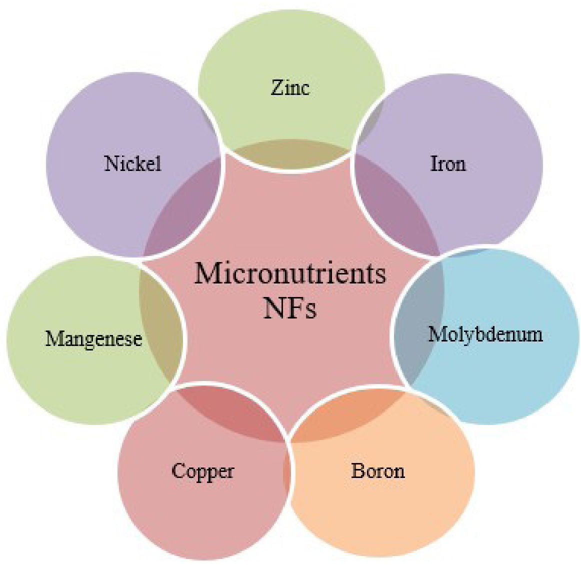

Figure 2: Shows the types of micronutrients NFs.

Table 1: Selected micronutrient elements' ranges and concentrations in plants [11].

Micronutrients	Range of concentration (ppm)
Zn	10 - 200
Fe	20 - 600
Cu	2 - 50
B	0.2 - 800
Mn	10 - 600
Mo	0.10 - 10
Ni	0.05 - 5

smaller leaves. It can also lengthen the time it takes for a crop to mature and result in lower-quality harvested crops [15].

Role of Fe in plants

Fe is a crucial element in the general growth of plants and is vital for controlling many cellular functions. In addition to controlling plant mitochondrial respiration, photosynthesis, metal homeostasis, and repair of nucleotides. Fe is essential for preserving several proteins' firmness [16]. Low Fe soils frequently cause chlorosis in plants and reduced photosynthesis, which lowers agricultural output and quality.

Role of Cu in plants

For plants to grow and flourish, Cu is an essential metallic element. In plants, Cu is crucial for cell wall metabolism, electron transport chain, lignin formation, photosynthesis, and mitochondrial respiration. Additionally, it is crucial for hormone signalling and the response to oxidative stress. Cu is also essential for the generation of ATP and the assimilation of carbon dioxide in plants [17].

Role of B in plants

The element B is crucial for healthy plant development but is frequently deficient in soils. B is a crucial trace element required for higher plants' physiological operation. B is one of the essential elements for a variety of crop species' yield quality, healthy growth, and development. B deficiency can result in nutritional diseases that have a detrimental impact on plant metabolism and growth [18].

Role of Mn in plants

Most species require the micronutrient Mn. Thus, a deficiency in Mn prevents these essential enzymes from performing their functional duties, which include scavenging reactive oxygen species, promoting seed germination, providing protection for fungi, and photosynthesis in plants. Freshly emerging leaves exhibit interveinal chlorosis as a symptom of a deficiency, but older leaves exhibit leaf necrosis, which appears as brown spots between veins [19, 20].

Role of Ni in plants

For the proliferation and developmental process of plants, Ni is an essential micronutrient. The metabolic activities of respiration, nitrogen metabolism, and photosynthesis all require Ni. In addition, Ni is crucial for the certain hormones, the formation of chlorophyll, and enzymes, as well as other compounds [21, 22]. Without sufficient Ni levels, plants cannot effectively utilize other nutrients, which results in stunted growth and lower yields.

Role of Mo in plants

For the proliferation and development of plants, Mo is a necessary metallic component. Mo is an important metal ion that plants naturally absorb. It is a crucial component of major enzymes in plants such as nitrate reductase, xanthine dehydrogenase, and aldehyde oxidase [23].

Entry of NFs in plants

Nfs are absorbed by leaves and roots. NPs can penetrate the root's endodermis and epidermis and then go to the xylem vessels, where they can propagate to the plant's upward part. Additionally, NPs can migrate from one plant component to another through the phloem and leaf stomata [24]. NPs smaller than the holes in plant cell walls may be able to pass through plasma membranes. Numerous studies demonstrate how aquaporin-bound carrier proteins and ion channels can allow NPs to enter plant cells [25, 26]. NPs may travel in an apoplastic or symplastic fashion once they have entered the cell. They can be transferred by plasmodesmata from any cell [27]. Table 2 shows the various types of micronutrients NFs impact on different crops.

Conclusion

Traditional fertilizers over fertilize the soil and cause microelements to leak into the deeper soil layers, groundwater, and surface water. Additionally, the common methods of nutrient administration are not particularly effective at making all the nutrients bioavailable to plants. Nanotechnology to solve our fundamental problem of raising agricultural yields and meeting the huge population demands to have a sustainable future. The use of micronutrient NFs in agricultural practices is a very recent and cutting-edge development. These NFs are made to deliver vital micronutrients to plants at the nanoscale, which may improve nutrient uptake, boost crop productivity, and promote general plant health. Plants and nanotechnology can work together to build fertilizer micronutrients for the intelligent distribution of nutrients that provide a plentiful supply of nutrient-rich food.

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Conflict of Interest

None.

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Table 2: Various types of micronutrients NFs impact different crops.

Nanomaterials	Plants	Application	Details	Ref.
ZnO	Cotton	Root	Total chlorophyll (139%), Growth (131%), total biomass (131%), carotenoids (139%), activities, total soluble protein contents (179%), POX (183%) and SOD (264%) were significantly elevated when compared to the untreated control.	[28]
ZnO	Sorghum	Root and foliar	Plant productivity was increased, as were N utilization efficiency and grain nutritional qualities as compared to the untreated control.	[29]
N and ZnO	Wheat, sesame, pearl millet, and mustard	Foliar	The average yield of pearl millet, wheat, sesame, and mustard improved by 4.2%, 5.35%, 24.24%, and 8.4%, respectively, when N and Zn NFs were used in conjunction with organic farming practices.	[30]
FeS	Mustard	Foliar	Induced plant growth and yield, as well as elevated antioxidant enzyme activity, as compared to an untreated reference.	[31]
Fe_2O_3	Tomato	Root	Compared to the untreated control, there was a rise in both overall biomass and plant size.	[32]
Fe_2O_3	Rice	Foliar	Increased biomass, a higher photochemical quantum yield, and higher chlorophyll content in maize are all indicators of the impact of FeO NPs on plant development.	[33]
CuO	Maize	Foliar and Root	When compared to the untreated control, both solutions were boosted maize regulated numerous enzyme functions and growth (51%).	[34]
Cu-chitosan	Tomato	Root	Improved stomata conductance (7%), plant growth (21 - 29%), fruit lycopene content (12%) and yield (30%), and leaf catalase (462%) compared to control.	[35]
MnO	Mung bean	Foliar	The foliar exposure of Mn NPs at 0.05 mg/L enhanced rootlet number (71%), biomass (38%), shoot length (38%), and root length (52%) compared to treatments with $MnSO_4$.	[36]
MnO	*Capsicum annuum*	soil	Both salt-stressed and unstressed seedlings greatly benefited from the addition of Mn NPs (0.1, 0.5, and 1 mg/L) to the soil.	[37]
ZnO and B	Pomegranate	Foliar	A study found that fruit productivity and quality could be improved by using modest amounts of B and Zn NFs.	[38]
Ni NPs	Wheat	Foliar	Chlorophyll a and b levels increased at modest doses of 0.01 and 0.1 mg/L, respectively.	[39]
$Ni(OH)_2$	*Vigna radiata*	Seed priming	NPs have ability to promote seedling growth and improve seed germination.	[40]
Mo	Green beans	Foliar spray	It encouraged the production of photosynthetic pigments with better N UE and the activity of the enzyme nitrate reductase.	[41]

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