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Revolutionizing Crop Nutrition: Exploring Nano Fertilizers in Agriculture

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Nutrients that have been coated or encapsulated in nanomaterials to allow for regulated release and gradual soil dispersion are known as nano fertilizers. These compounds release nutrients more slowly than the commonly used bulk fertilizers, these release nutrients that are required by plants in slow process to prevent the leaching of the nutrients. The macro elements like Nitrogen, Phosphorus and Potassium are very important to plant for growth and development. Secondary nutrients like Sulphur, Calcium and Magnesium play an important role in plants like enzyme production, plant internal development, and to get good yield. Micronutrients play an important role in maintaining plants internally. The bulk application of fertilizers leads to soil, water, and environmental pollution. The application of nano fertilizers as a foliar spray increases the absorption of nutrients and decreases environmental pollution. Nano fertilizers reduce the use of conventional bulk fertilizers, therefore reduces the production cost to growers. These are very slow

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release in nature so maximum nutrients are absorbed by plants. These are very highly reactive in nature so sometimes causes phytotoxicity when excess amount is applied to plant than the recommended amount. The application of nano fertilizers presents a promising avenue for sustainable agriculture, offering benefits such as controlled nutrient release, improved crop yield, and reduced environmental impact. While challenges such as phytotoxicity and dosage control must be addressed, nano fertilizers hold great potential as a transformative solution to enhance agricultural productivity while mitigating environmental degradation.

Keywords: Nanofertilizer; soil; nutrients; agriculture; conventional fertilizers; nano particles; phytotoxicity.

1. INTRODUCTION

The University of Tokyo's Norio Taniguchi is credited for coining the term "nanotechnology." The Greek word "nano," which meaning "dwarf," is where the name "nanotechnology" originates. Thus, the term "nanotechnology" describes the development and use of materials, tools, and systems by manipulating their structure and behaviour at the nanoscale [1]. A substance that provides nutrients to crops in one of three ways is called a nano fertilizer. The nutrition can be administered as particles or emulsions of nanoscale dimensions, coated with a thin protective polymer film, or enclosed inside nanomaterials like nanotubes or nanoporous materials. Now a days the world population is increasing drastically, to feed all these populations a huge amount of food is needed and huge area of cultivation of crops needed, for cultivation of crops, application different types of chemical fertilizers are needed. The large amount of application of chemical fertilizers leading to pollution of water, soil, and atmosphere [2], to minimize the use of huge amounts of chemical fertilizers the application of nano fertilizers is needed [3]. There is a need to change conventional farming to smart farming by using these nano fertilizers. After biotechnology nanotechnology is the 5th revolutionary technology. In this we study the application of (1-100nm) nano particles. Noval tools are designed to deal with these nano particles at field level. With the aid of nanotechnology, conventional fertilisers can be created in new or modified forms, or bulk materials for fertilisers can be extracted from various vegetative or reproductive plant parts using a variety of chemical, physical, mechanical, or biological techniques. The goal of nano fertilizers is to increase soil fertility, productivity, and the quality of agricultural products. One can create nanoparticles from completely bulk materials [4]. Nanofertilizer technology is a very innovative technology to get maximum yield from field by using nano particles. The efficiency of conventional fertilizer is 30-35%, 18-20% and 35-40% for N, P and K respectively to increase the efficiency and to reduce the wastage of chemical fertilizers the need I there to apply the nano fertilizers. Nano fertilizers have extensive surface area and can hold nutrients more efficiently than conventional fertilizer. The current era using zeolite based nanofertilizer [5]. These days, nanotechnology is offering a variety of nanomaterials and nanodevices that play a special role in agriculture. For example, nanobiosensors can be used to measure soil moisture content and nutrient status and are also useful for managing water and nutrients specific to a given site. Nanofertilizers can effectively manage nutrients, while nanoherbicides can selectively control weeds in crop fields. Nanonutrient particles can boost seed vigour, and nanopesticides can effectively manage pests. Alginate and chitosan nanoparticles can be used as a material carrier for herbicides, particularly paraquat [6]. Nano fertilizers are produced at nano scale in this nano scale the physical and chemical properties are differed from the bulk conventional fertilizers. Physical and chemical characteristics of nanomaterials differ from those of bulk materials. Similar stories were given. When applied directly to crop plants, rock phosphate nanoparticles may prevent fixation in the soil. Similarly, since silicic acid, iron, and calcium are not needed for phosphorus fixation, the availability of phosphorus to crop plants may be increased when used in nano form [7].

2. NANO FERTILIZERS VS CONVENTIONAL FERTILIZERS

2.1 Advantages of Nano Fertilizers [8]

Nano fertilisers have several advantages over conventional fertilisers, including increased soil fertility, crop quality and yield, reduced cost and maximum profit, and nontoxicity and less impact to humans and the environment. The agricultural sector is facing mounting pressure to meet the ever-increasing demands of the steadily expanding human population. Applications of nano fertilizer in agriculture could present a chance to attain sustainability in the production of food for the world. By using controlled or gradual release mechanisms, nano fertilisers can adjust the amount of nutrients available to crops. The coating or cementation of nutrients with nanomaterials is linked to this kind of sluggish nutrition delivery [9]. Growers can boost crop development by utilising this gradual nutrient delivery, which provides plants with regular, long-term nutrient delivery. For instance, instead of the 4–10 days that conventional fertiliser release nutrients, they can release them over 40–50 days in a slow-release manner [10]. Half of the applied fertiliser is lost to leaching in conventional nutrient management systems, or it becomes unavailable for the plant due to high availability that impedes roots' ability to absorb it or occasionally has harmful consequences on the plant. Additionally, the demand for transportation and application expenses is decreased with nano fertilizers [11]. The main advantage of nano fertilizer is that they can synthesise in manufacturing units according to the plant requirements [12]. On other hand nano fertilizers can increase the bio availability of essential nutrients to the plants.

As having many advantages, the nano fertilizers also have some of the disadvantages to consider.

3. DISADVANTAGES OF NANO FERTILIZERS

Nano Fertilizers are highly reactive in nature. Since different plants react to different nanomaterials in a dose-dependent manner, phytotoxicity is another concern in this area [13]. Nano fertilizers are very reactive in nature because they have large surface area and they are miniature in size [14]. According to certain research, nanoparticles have a phytotoxic effect. The uptake, translocation, transformation, and accumulation of NPs in plants known as phytotoxicity depend on the kind of NPs, their composition, size, shape, and surface features, as well as their application technique, species, and dose [15]. To research and comprehend the uptake and translocation of nanofertilizers, the potential transformation of nanoparticles when they interact with soil and plant compounds, and the accumulation of NPs in various plant tissues, it is crucial to examine the degree of toxicity of each NP in any given crop [16].

4. EFFECT OF NANO FERTILIZERS ON SEED GERMINATION

The speed and uniformity of the seedlings that will protect buds from damage caused by unfavourable environmental circumstances determines the growth and productivity of plants. Temperature, moisture, salinity, and drought are the main environmental elements that affect seed germination and the subsequent growth of seedlings [17]. Increased production of forage and medicinal plants in rangelands and agricultural fields is dependent on efficient seed germination [18]. Plants that have rapid and uniform seedling emergence eventually establish themselves well and develop deep roots [19]. Several investigations have demonstrated that the use of nanoparticles (NPs) has a positive impact on both plant growth and development and seed germination. This is because the small size and special physicochemical characteristics of nanoparticles make them an effective seed priming strategy [20]. Nano fertilisers increase the following: rate of photosynthesis, which leads to more production and translocation of photosynthets to different parts of the plant; dry matter production; chlorophyll production; plant height; vigour; growth parameters (leaf area, leaf area index, number of leaves per plant); and seed germination [21]. Numerous studies found that nano fertilisers had a major impact on seed germination and seedling growth, indicating their impact on both seed and seed vigour. Nano fertilisers are easily absorbed by seeds and provide more nutrients to the developing seedling, resulting in a healthy plant with longer roots and shoots. However, if concentrations of the fertiliser exceed recommended levels, the plant's ability to germinate and grow seedlings may be inhibited [22]. When compared to bulk zinc sulphate, nano ZnO showed greater rates of root growth and germination in peanut seeds [23]. Numerous studies have shown that applying nanofertilizers greatly increases crop yield compared to control or no application at all. This is primarily since plant parts grow more quickly and that metabolic processes like photosynthesis increase the accumulation and translocation of photosynthetic units to the economically valuable parts of the plant. Crop yields are greatly increased when nanoparticle fertiliser is applied foliarly [24]. By accelerating the pace of reaction or synthesis process in the plant system, nano fertilisers improve the surface area and nutrient availability to the crop plant, helping to increase these quality characteristics of the plant (such as protein, oil content, and sugar content). When zinc and iron are applied to plants, the amount of protein, starch, IAA, chlorophyll, and total carbohydrates increases in the grain. The application of nano Fe_2O_3 Increases the rate of photosynthesis and yield in the peanut plant.

4.1 Nitrogen Nano Fertilizer

In plant cells, nitrogen is a crucial part of numerous structural, genetic, and metabolic components. It is a significant part of chlorophyll, the substance that allows plants to convert carbon dioxide and water into sugars through the utilisation of solar energy. It also makes up a sizable portion of amino acids, which are the building blocks of proteins. While some proteins function as the structural building blocks of plant cells, others function as enzymes that catalyse several biochemical events essential to life. A component of energy-transfer molecules like ATP (adenosine triphosphate), nitrogen enables cells to store and utilise the energy produced during metabolism. Finally, nitrogen plays a key role in nucleic acids like DNA, the genetic material that permits the growth and reproduction of cells (and eventually entire plants). As nitrate (NO3-) ions, which are available to plants, ammonium (NH4+) ions, and organic nitrogen molecules are the three general types of nitrogen that exist. Not all the nitrogen is fully available to the plant. This is a result of negatively charged nitrate's typical lower affinity for the surfaces of soil particles, which prevents it from sorbing on soil easily [25]. To address the issues related to nitrogen leaching during fertilisation, various methods were employed, including urea coated with polyolefin resin, urea coated with neem, and urea coated with sulphur, to regulate the release of nitrogen. However, the release of N is delayed during periods of high N content, and slow-releasing fertilisers are sometimes costly. By adding cation exchangers to fertiliser as additives to regulate NH4 + release, N loss can also be decreased. Crop output is increased overall when nutrients are retained by zeolite and released on schedule. Clinoptilolite zeolite (CZ) is a porous material that has a high affinity for NH4+ and a high cation exchange

Table 1. Difference between nano fertilizers vs conventional fertilizers

S. No	Property	Nano Fertilizer	Conventional Fertilizer
1	Efficiency of nutrient uptake	In crop production using a nano structured formulation could improve soil nutrient uptake ratio and fertilizer use efficiency while using overall less fertilizer.	For roots, bulk composite is unavailable and reduces efficiency**.**
2	Solubility and dispersion of nano fertilizer	Micronutrient minerals are at nano scale may decrease soil absorption and fixation and increase bio availability to plants and improve solubility and dispersion of insoluble minerals in soil.	reduced solubility and big particle size resulting in decreased bioavailability for plants.
3	Time that nutrients release effectively	Fertilisers with a nano structured formulation can increase the amount of time that they effectively give nutrients to the soil**.**	When delivered, the plants use what's left behind, converting the remainder to insoluble salts in the soil.
4	Controlled release rates	Water soluble fertilisers can have their nutrient release rate and pattern accurately regulated by encasing them in semipermeable membrane envelopes covered with wax, sulphur, and resin-polymer.	Over usage of fertilisers can lead to toxicity and upset the soil's natural equilibrium.
5	Rate of loss of nutrients from fertilizer	A formulation with nano structure can slow down the rate at which nutrients from fertilisers leak or leach into the soil.	High rate of loss due to raining, drifting, and by leaching.

capacity (CEC, up to 300 c mol (p+) kg^{-1}) [26] has been applied to lower farm manure's NH3 emissions [27], to eliminate NH3 $_3$ toxicity to plants. It has been observed that adding clinoptilolite zeolite (CZ) to sandy soil increases soil surface area and CEC, decreases NO3- and NH4+ concentrations in the leachate, and improves soil moisture retention [28]. Because urea nitrogen is less expensive per unit of N, it has been the most widely utilised N-source. However, losses from agricultural systems due to ammonia volatilization to the atmosphere may result in a reduction in the N usage efficiency of urea. This can reach severe values, about 80% of the applied N, and is one of the main causes of the low urea efficiency. The ammonium that CZ retains is often slowly released into the soil through nitrification and cation exchange [29]. Because of its high CEC, clinoptilolite zeolite has been utilised as an NH4+-loaded exchange fertiliser and to minimise NH3 emissions from farm manures.

4.2 Phosphorous Nano Fertilizer

As a component of several important plant structural chemicals and as a catalyst in the conversion of several important metabolic events in plants, phosphorus is an essential nutrient. The most crucial nutrient for plants' ability to store and transfer energy is phosphorus [30]. The two types of phosphates that are most crucial for energy transfer are adenosine di- and triphosphates (ADP and ATP). It is also a crucial structural element of coenzymes, phospholipids, sugar phosphates, phosphor-proteins, nucleic acids, and plant metabolic substrates. Early crop P supply is crucial for the development of the crop's reproductive structures. Increased root development, stronger stalks and stems, better flower formation and seed production, more uniform and early crop maturity, increased legume N-fixing capacity, improved crop quality, and increased resistance to plant diseases are some specific growth factors that have been linked to phosphorus. As the experiment conducted by [31], Plants in synthetic soils may benefit from slow-release fertilisation using zeolite and phosphate rock combinations due to their solubility and cation-exchange in NH4+ and K-saturated clinoptilolite. This is achieved by ion-exchange reactions and dissolution. Crops' use of fertiliser P varied from 18 to 20% depending on the year it was administered. The remaining 78–80% joins the soil P pool and is released to the crop throughout the course of the ensuing months and years. Both phosphate and ammonium ions are liberated from the phosphate rock by the zeolite's absorption of Ca2+. In contrast to the equilibrium that was formed by the leaching of highly soluble phosphate, controlled-release phosphate fertilisers (like super phosphate) release phosphate through a particular chemical reaction in the soil. To restore equilibrium, more phosphate and ammonium are released via the chemical reaction when phosphate is absorbed by plants or by soil fixation. The ratio of P rock to zeolite can be changed to regulate the rate of phosphate release. When soil pH decreases due to ammonium ions being transformed to nitrate, phosphorus is also liberated from the rock. This method of nutrient delivery is driven by plant need. N, P, and K were supplied by zeoponics to the plant when needed. In essence, the procedure combines ion exchange processes with dissolution reactions. The dissolution and ion exchange reactions are triggered by the nutrients that plant roots absorb from the soil solution, drawing nutrients out as needed. The zeolite is then "recharged" with more nutrients that have dissolved. By creating a replenishable and balanced nutrient supply in the plant root zone, zeoponic systems boost nutrient retention, decrease environmental nutrient losses, and minimise fertiliser requirements. According to study of [32], the PO4-release pattern of a surface changed in a percolation reactor employing different nanoclays and zeolite. It has been demonstrated that nano-formulations release phosphate for 40–50 days, whereas conventional fertilisers only release nutrients for 10–12 days. According to a review of the literature, surface-modified zeolites are a viable tactic to increase P use efficiency, which in conventional systems seldom exceeds 18–20%.

4.3 Potassium Nano Fertilizer

Studies on the slow and steady release of K from nano-zeolites suggested that this could be because of the zeolites ability to exchange ions with certain nutrient cations. As a result, zeolites can be a great tool for plant growth, providing extra essential cations and anions to plant roots. Numerous enzymes necessary for respiration and photosynthesis, as well as those that make proteins and carbohydrates, are activated by potassium [33]. Potassium also involves in turgor pressure of guard cells and opening and closing of stomata and involves in maintaining the osmotic potential of the cell. It has been observed that 50-90% of potassium losses into environment, and not available to plants it causes great economic loss to the farmers [9]. Chemical fertilizers increase the cost of production as well as increase the environmental pollution. Consequently, to maintain healthy soil structure and a clean environment while providing essential nutrients for vine development and productivity, it may be beneficial to employ and experiment with different fertilisation techniques [34]. The development and deployment of novel fertiliser types have found a new application in nanotechnology. The word "nano" comes from the Greek "many small." One billionth of a metre is what is meant by the term nano. Nanoparticles are defined as particles with a minimum dimension of less than 100 nm [35,36] reported a gradual and consistent release of K from nano-zeolites, suggesting that this could be attributed to the zeolites' ability to exchange ions with specific nutrient cations. As such, zeolites can serve as a highly effective plant growth medium, providing plant roots with extra essential cations and anions. More dissolved nutrients can be added to the zeolite to "recharge" it. The order of their ion exchange selectivity on zeolite was found to be K+ > NH4 + > Na+ > Ca2+ > Mg2+ [37]. potassium (K+) - loaded zeolite (K-Z) as a slow-release fertiliser and examined the variations in the soil's nitrogen and potassium concentrations as well as the growth traits of hot peppers. Although dynamic equilibrium and potassium fixation in soil work together to maintain potassium availability in soil, nanotechnology can enhance nutrient availability and controlled release even more.

5. SECONDARY NUTRIENTS

5.1 Sulphur Nano Fertilizer

The recognition of sulphur as the fourth essential component for plants, following nitrogen, phosphorus, and potassium, is growing quickly. Although sulphur and phosphorus are equally important elements for plant growth, sulphur received less attention for a long time because sufficient soil quality was achieved through fertilisers and atmospheric inputs. In the earth's crust, sulphur is a naturally occurring element that is ranked thirteenth in terms of abundance [38]. According to the study's hypothesis, sulphur fertilisation is primarily limited to crops, and the use efficiency of traditional sulphur fertilisers hardly surpasses 20%. To increase use efficiency, this calls for the use of slow-release nano-fertilizer in crop production systems.

5.2 Calcium Nano Fertilizer

Fruit skin flexibility is increased by nano Ca, which promotes fruit growth and stiffness, improving the fruit's resistance to storage and transportation. It guards against and treats calcium shortages as well as related infections such apical rot, fruit breaking, and necrosis in the apical leaf. Calcium nano fertilizers considerably lower disease and insect pest infestations while providing structural support for plant cell walls [39].

5.3 Magnesium Nano Fertilizer

Magnesium nano fertilizers are a crucial part of many enzyme systems that produce energy, synthesise proteins, and control development. Plants need nano magnesium to speed up photosynthesis, which is necessary to give leaves their green hue. Chlorophyll cannot absorb solar energy required for photosynthesis if magnesium is not present. Older leaves are initially affected by magnesium shortage, turning yellow around the margins and in between the veins. Plants need nano magnesium to speed up photosynthesis, which is necessary to give leaves their green hue.

5.4 Nano Micro Fertilizers

According to studies conducted by [40]revealed that ryegrass root tissue was penetrated by zinc oxide nanoparticles, which enhanced germination. Boron (B), Zinc (Zn), Manganese (Mn), Iron (Fe), Copper (Cu), Molybdenum (Mb), and Chlorine (cl) these 7 are micronutrients. These nutrients constitute <1% of most of the plants dry weight. Micronutrients are necessary for healthy plant growth and successful crop production even though they are needed in very small amounts. Many Asian nations have extensive micronutrient deficiencies because of calcareous soils, high pH, poor organic matter, salt stress, ongoing drought, high bicarbonate concentration in irrigation water, and uneven NPK fertiliser application. Micronutrient deficiency can lead to some adverse effect on plants like low crop growth and development, low yield and low quality and the internal morphology of the plant also affected [41]. According to [42] the solubility of minerals in small amounts and the sequestration effect of exchange are responsible for the gradual release of zinc. This allows trace nutrients to be released to zeolite exchange sites, where plants may more easily absorb them. Since zinc is a necessary nutrient for plants, the zinc rich ZnO NPs raised the amount of IAA in the roots (sprouts), indicating an increase in the rate at which plants are growing [43]. Although boron is a necessary element for plants, excessive amounts of it can be harmful to other living things. Numerous researchers have investigated the adsorption of boron by clays, soils, and other minerals in detail [44]. It was demonstrated that the zinc oxide nanoparticles entered the ryegrass's root tissue and enhanced germination [40]. The component molybdenum is necessary for the plant enzyme nitrate reductase. Furthermore, Mo is a crucial component of nitrogenase, a type of nitrogen-fixing bacteria that is necessary for legume crops.

6. NANO FERTILIZER IN WHEAT

In a field experiment conducted on nano fertilizers and wheat growth and yield are taken.

6.1 Phyto Toxicity Due to Nano Fertilizers [45]

The process of Phyto toxicity caused due to nano fertilizers remains unknown. Still, they would mostly pertain to the nanomaterial's surface area, chemical composition, surface area, and particle size. The nanomaterial's phytotoxicity may be connected to two distinct outcomes: (A) stress or stimulation brought on by the nanomaterial's size, shape, or surface; and (B) a chemical toxicity that depends on its chemical makeup. Although it has been established that the solubility of metal oxide nanoparticles greatly influenced the response of cell cultures, dissolution of the nanoparticles alone cannot explain nanoparticle-mediated toxicity [46]. Silica NPs, CNMs, and metallic NPs are among the many reports on NP interactions with plants that are now accessible. Because metallic nanoparticles (NPs) are rapidly absorbed by roots and can supply plants with readily assimilated critical micronutrients, most studies have focused on them [47]. It is important to highlight that, depending on the physicochemical characteristics, NM interactions with plants can have both beneficial and detrimental effects. Thus, below are reports on some of the most used NPs as nonfertilizer, their phytotoxic effects on various plant systems, and the bioassays used to evaluate such effects. Zinc, copper, iron, manganese, and their oxides (TiO_2, Al_2O_3, CuO, and Fe_2O_3) are commonly used in model plants for their phytotoxicity [48,49].

Table 2. Impact of different nano fertilizers spray on plant height, chlorophyll content and N, P, and K concentration in leaves

Treatment No	Plant height (CM)	Spike length (CM)	Chlorophyll content	N%	P%	K%
T1	67.22	8.44	43.44	2	0.22	1.22
T2	76.68	11	48.66	2.76	0.46	1.88
T3	73.33	10.77	47.84	2.53	0.33	2.20
T4	71.55	9.97	45.78	2.34	0.40	2.33
T5	81.55	11.66	55.64	2.88	0.60	2.66
T6	87.77	12.22	58.22	3.17	0.66	2.88
T7	77.78	11	50.55	2.55	0.46	2.22
$LSD_{0.05}$	2.142	1.098	1.133	0.303	0.017	0.108

Table 3. Impact of application of various sources of nano fertilizers on biological yield and grain production in ton per ha, and 1000 grain weight and harvest index percent, protein percent and fertilizer productivity Kg^{-1}

Treatment No.	Biological yield Mg ha^{-1}	Grain yield Mg ha^{-1}	Weight of 1000 seed in Gram	Harvest index in %	Protein content in %	Fertilizer productivity Kg Kg^{-1}
T1	11.499	4.060	39.69	35.27	11.94	0.00
T2	12.449	5.305	45.78	42.55	13.01	1245
T3	12.289	4.886	44.84	39.79	12.37	825
T4	12.138	4.575	42.21	37.65	12.15	515
T5	13.047	5.642	47.25	43.18	13.33	1581
T6	13.364	5.996	47.88	44.96	13.69	1936
T7	12.674	5.198	45.57	41.07	12.90	569
$LSD_{0.05}$	0.470	0.406	1.286	4.460	0.614	216.1

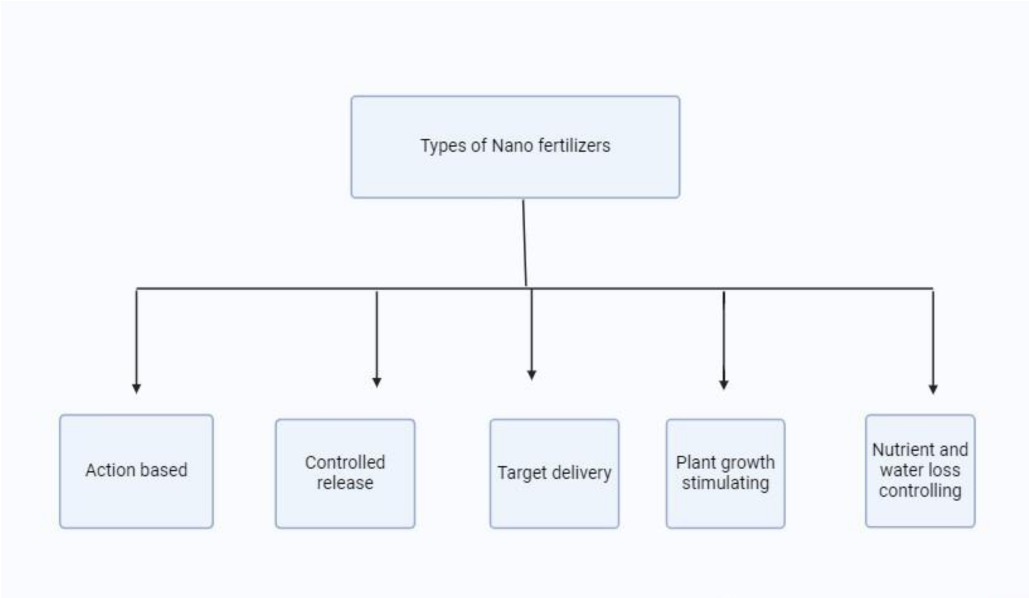

Fig. 1. Types of nano fertilizers

Table 4. Phyto toxicity due to nano fertilizers

S.No	Type of nano materials	Size of nano material	Concentration	Trial plant	Impacts	References
1	CuO Nano particles in humic acid	43 nm	0,2,5,10,20,50,100 mg/l	*Oryza sativa*	caused abnormalities in the morphology, ultrastructure, and suppression of root extension.	Rajput *et al*, [50]
2	Silica nano particles	7,12,22 nm	540-1820 mg/l	*Allium cepa*	impacted the seedlings' germination and root elongation Chromosome abnormalities were observed in root meristems using cytogenetic analysis.	Da silva and Monteiro [51]
3	ZnO nano particles	10nm	400-800mg/kg	cucumber	ZnO NPs has considerably raised the starch content at 400 mg/kg.	Zhao L *et al*, [52]

S.No	Type of nano materials	Size of nano material	Concentration	Trial plant	Impacts	References
4	C60	29-38 nm		*Lemna gibba*	Chlorophyll a and b contents as well as the oxygen produced by chloroplasts were significantly reduced.	Santos Sm *et al*, [53]
5	SiO_2 nano particles	35nm	2000mg/l	Bt-cotton	reduction in the biomass of the roots, shoots, and plant height impacted the levels of micronutrients in roots, including Cu, Mg, and Na	Le VN *et al*, [54]
6	Ag nano particles	20nm	50,500,2000 mg/kg	*Arachis hypogea*	reduction in crop output and plant growth	Rui M *et al*, [55]
7	Graphene	1nm	500-2000mg/l	Red spinach, Tomato and Cabbage	inhibiting impact on biomass and plant growth Both the quantity and size of the leaves had significantly decreased.	Begum P *et al*, [56]
8	CuO nano particles	30-50nm	10g/l	*Hordeum sativum*	reduced growth through altering the rate of transpiration, the maximal quantum yield of photosystem II, and the elongations of the shoots and roots.	Rajput *et al*, [57]
9	Green synthesized Au nano	30-113 nm	5.4 ppm	*Allium cepa*	increased germination, height of the	Acharya P *et al*, [58]

S.No	Type of nano materials	Size of nano material	Concentration	Trial plant	Impacts	References
	particles				plant, length, diameter, and surface area of the leaves	
10	Y_2O_3 nano particles	20-30 nm	50 and 100 mg/l	Seedlings of *Oryza sativa*	Seed germination was delayed	Zhao X *et al*, 59]
11	CeO_2 nano particles	16.5 nm	1000 and 2000 mg/kg	Lettuce	Chlorophyll content was decreased	Zhang P *et al*, [60]

7. CONCLUSION

Nano fertilizers are a very good source for the nutrients that are required by plants, these nano fertilizers release nutrients that are required by plants in a controlled way, that plant completely get nutrients released by nano fertilizers. Use of bulk fertilizers leads to environmental pollution. By using nano fertilizers, it reduces pollution and increases the productivity of crops. Nano fertilizers are very precise and slow releasing. They release nutrients slowly into plants rhizosphere so all the mineral present in nano fertilizer can easily be absorbed by plants. Although nano fertilizers are good to plants, they also have some disadvantages like they are highly reactive in nature excessive application of nano fertilizers leads to phytotoxicity to plants. So optimum limit of application of nano fertilizer can cause good effect to plant [61].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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