Review Article

Nano Fertilizer: A Boon to Environment Friendly Agriculture

Abstract

For modern agriculture food production systems (FPS) to feed the expanding population, improving nutrient usage efficiency (NUE) with little environmental risk has become essential. A novel approach to the problem of poor or falling nutrient use efficiency (NUE) with a little environmental impact has emerged: nanotechnology with nanoscale inputs for the development of nanoagri-inputs (NAIPs). The study of nanotechnology holds great promise for providing modern intensive agriculture with long-lasting solutions to its pressing problems. Nanotechnology uses small-sized materials called nanoparticles (1–100 nm), which offer special properties and advantages. Large surface area to volume ratio provides chance for better and more efficient interaction of nanoparticles to target areas in addition to many other advantages.In addition to providing crop production systems with sustainability, nano-fertilizers have the potential to meet plant nutritional needs without reducing crop yield.These nano-fertilizers take advantage of the dynamics of surface area, size, shape, and bio-assimilation. Their effectiveness was assessed based on studies conducted in several places with multiple crops over various crop seasons, both by research institutes and on the fields of progressive farmers spread out over 11,000 locations and 94 different crops in India. Separate tests for bio-efficacy, biosafety, toxicity, and environmental compatibility have been conducted on nano-nitrogen, nano-zinc, and nano-copper.

Keywords: Nutrient use efficiency, Nanofertilizers, Nanoparticles, Crop response to Nanofertilizers, Sustainable agriculture

Introduction

Chemical fertilizers have been considered an essential component of contemporary agricultural production methods since the green revolution, but they also have linked environmental and ecological effects. Leading contributors to environmental pollution and climate change have been leaching and gaseous emissions from agricultural areas.Since the start of the green revolution, intensive agricultural methods have developed and been found to be unsustainable due to the utilization efficacy of applied chemicals, especially mineral fertilizers, remaining below 30%. In order to increase crop output and nutritional quality, fertilizers have become increasingly important, especially with the emergence of fertilizer-responsive crop types. Since it is a component of chlorophyll and numerous proteins and enzymes, nitrogen is the most important mineral nutrient needed by agricultural plants. As a result, it is crucial for the vegetative growth of crops. Nitrate (NO_3) and ammonium (NH^+_4) are the two forms of nitrogen that plants can absorb. Through the nitrate leaching, denitrification, and ammonia volatilization processes, nitrogen is lost. A growing worry is the loss of mineral nutrients through leaching and runoff to surface and ground water, as well as the extensive volatilization that results from lost revenue and environmental damage. Eutrophication, the process where algae develop on the surface of water bodies as a result of nutrient-rich water obstructing fish oxygen delivery, has shown that conventional application tactics substantially overuse chemical fertilizers. Additionally, because nitrous oxides are greenhouse gases and are released as a result of nitrogen volatilization, they contribute to global warming. It is also important to note that ammonium ions combine with alkaline rainwater to produce ammonia gas, which escapes into the atmosphere and causes contamination of the environment. Nitrates and ammonium ions accumulate in the leaves of crops, especially green vegetables, if there is an excess of nitrogen, which is harmful to human health. Additionally, nitrate-rich diets have reportedly been linked to a number ofhuman ailments like bladder and gastrointestinalboth cancer and methemoglobinemia. It isbeing under pressure to supply the necessary quantityonly when they are urgently needed, active agentsneeded. Consumers and environmentalists call in favor of lowering the usage of synthetic fertilizers lessen the impact of pollutants and residue on form produces and keeps agroecosystems intact. It is extremely regrettable that modern Profit-driven farming practices have proliferated unstable primarily because of inadequatenutrient usage efficiency, unbalance, and overuse of fertilizer application. Crop production must be sustainable, so it is necessary to look into other nutrition sources and change those that are currently used. Utilizing nanoparticles with a size of less than 100 nm, nanotechnology may present an unheard-of chance to create concentrated supplies of plant nutrients with increased absorption rates, effective use, and minimal losses. By encapsulating plant nutrients in nanomaterials, using a thin coating of nanomaterials on plant nutrients, and distributing in the form of nano-sized emulsions, nano-fertilizers are created. In plant leaves, nano-pores and stomatal apertures enable the uptake of nanomaterials and their penetration deep inside leaves, increasing nutrient utilization efficiency (NUE). resulting in greater nutrient utilization effectiveness (NUE). Through the nanosized (50–60 nm) tubes between cells called plasmodesmata, nutrients are transported and delivered more effectively and efficiently by nano fertilizers. Field crops produce more and have better nutritional value thanks to nano fertilizers' greater NUE and noticeably lower nutrient losses. Productivity increases of 6–17% are also a result. However, the main problems preventing their widespread use as plant nutrient sources are their manufacture and availability, their adequate effectiveness in law, and associated risk management. Using its indigenous innovation capabilities, IFFCO has developed and produced Nano Urea, Nano Zinc, and Nano Copper as exclusive nano inputs. Nano Biotechnology Research's R&D initiatives Gujarati Center (NBRC) Kalol. such microscopic Products take advantage of form dynamics, length, breadth, and bioassimilation. The research groups examined nano fertilizers through 11,000 on-farm trials on progressive farmers' fields across the nation in 2019–20, encompassing 94 crops and many locations and multiple crops. The advantages of nanofertilizers (Nano N, Nano Zn, and Nano Cu) in general and IFFCO's Nano-Urea, Nano-Zn, and Nano Cu in particular for improving nutrient use efficiency, crop productivity, and produce quality are reviewed in this research.

A scenario with increased multinutrient deficits, decreased nutrient usage efficiency, and fertilizer use

Increasing the amount of land under cultivation is difficult in India, therefore productivity improvements must account for a major portion of any increase in food grain production. The productivity of food grains has increased dramatically, from 522 kg ha-1 in 1950–1951 to 2,235 kg ha-1 in 2017–2018. However, the loss in fertilizer factor productivity in relation to the production of food grains suggests nutrient depletion in the soil pool and a decrease in NUE. This has led to a decline in the crop's response to the application of plant nutrients, which went from 15 kg of food grain per kg of NPK during the fifth plan (1974–79) to less than 6 kg in the eleventh plan (2007–12) (Prasad 2013), which further decreased to 2.7 food grain per kg of NPK in irrigated cropping systems. Instead, fertilizer usage efficiency (FUE), which depends on a number of variables such as nitrogen uptake efficiency and soil health, impacts our agricultural and environmental stability. With regard to the problem of declining FUE, innovative fertilizers can successfully implement the 4R principles. In India, urea-N is the most often consumed fertilizer, which is unbalanced. As a result, the ratio of NPK consumption has increased from 4:3.2:1 in 2009–2010 to 7.0:2.8:1 in 2019–2020. After a brief adjustment, the use of nitrogen has increased post-NBS 2010. In areas where nitrogen is applied more frequently, there needs to be a balance between this and an increase in this area. Sulphur (S), zinc (Zn), and boron (B) shortages have been widely reported in India's grain, pulse, and oilseed crops. Fruit harvests have been found to be deficient in copper. Accordingly, it is necessary to identify and address the block-specific micronutrient deficiencies for increased crop yield and farmer profitability. Crops that have been bio-fortified with micronutrients will also address the micronutrient shortages of people and animals. The issues that farmers, researchers, and policymakers are currently facing can only be met by improved NUE of major and micronutrients with better soil health and agronomic management methods.

Using urea improperly is a growing source of concern

An extremely serious issue is the imbalanced and careless administration of urea. For the benefit of the environment and their own profitability, farmers have been urged to cut back on their usage by at least 25%. In light of the sustainability of complete agricultural production systems and biogeochemical cycles, this topic needs to be reexamined. For the majority of the crops in India, urea makes up over 82 percent of the nitrogenous fertilizers used. Every year, urea is applied to a variety of crops in amounts of about 33 million tonnes(Mt).

Comment [C1]: tons

Table1:Urea production, import, and consumption over the previous five years(in '000 MT)

Year	Production	Import	Urea Consuption		Total
			Kharif	Rabi	
2016-17	24201	4971	14356	15258	29614
2017-18	24023	6011	14832	15062	29894
2018-19	23899	7555	15448	16571	32019
2019-20	24455	9124	15369	18326	33695
2020-21	24603	9828	17782	17260	35043

Ref.: Yogendra Kumar, *et al* 2021.

It will be consumed at a level of 35 Mt. Over a period of years, there has been a corresponding rise in urea production, import, and consumption. Over time, the amount of urea imported has increased, reaching 9.12Mt in 2019–20 and 9.82Mt in 2020–21. A year's worth of urea subsidies provided by the Indian government's budget are made up of 26 percent of subsidies on account of urea imports. Therefore, it is necessary to stop the consumption of urea from rising by using it wisely, investing in R&D, launching new goods, and implementing modern policy changes. As a result of improving nitrogen usage efficiency, nano fertilizers will be crucial in slowing down the demand for urea, lowering urea imports, and lowering the subsidy load.

Table 2: Subsidy paid by Government of India for Urea during last 3 years (Rs. Crore)

Year	Indigenous	Urea Imported	Urea Total
2016-17	40000	11257	51257
2017-18	36974	9980	46954
2019-20	32190	17155	49345

THE KEY TO SUSTAINABILITY IS INNOVATIVE FERTILIZERS

In addition to improved nutrient uptake efficiency, new and innovative fertilizers also assist the environment by leaving less of a carbon imprint. The fertilizer business was a pioneer in developing and introducing improved efficiency fertilizers (EEF) for the niche market. A high-tech fertilizer that is both innovative and economically viable could be a true solution for the heavily subsidized Indian fertilizer sector. The development of agricultural intensification strategies that enhance food output per unit of inputs and resources is possible with the help of nanotechnology. Due to its size advantage and regulated manufacturing process using chemical, physical, and biological techniques, nanotechnology-based fertilizers have become a viable choice to fill this gap in the market for traditional and novel fertilizers.

Defined and characterized are nano fertilizers

By definition, nano-fertilizers are "synthesized or modified forms of traditional fertilizers, fertilizer bulk materials or extracts of various botanical, microbial, or animal origin manufactured by chemical, physical, mechanical, or biological methods with the aid of nanotechnology but not limited to it." Additionally, traditional bulk fertilizers can be used to create these nanoparticles. Nano fertilizers have dynamic and distinctive physical and chemical properties at the nanoscale. They have increased absorption and availability due to their higher surface area to volume size ratio and nano size. Nano-fertilizers have a particle size of less than 1-100 nm in at least one dimension, allowing for better uptake from soil or leaves and the creation of more photosynthates and biomass, all of which are necessary for healthy crops. Comparatively to conventional fertilizers, nano-fertilizers generate very little salt accumulation in soil and offer advantages in terms of application and small requirement, slow release mechanism, decrease in transportation and application cost. Due to the improved bioavailability of nutrients, they efficiently meet crop nutrient needs. Through biofortification, nano-fertilizers applied to the foliage improve crops' NUE and nutritional value.

NANOFERTILIZERS' PURPOSE

In order to enhance food production in the twenty-first century, agriculture must face a number of issues, including the world's population's rapid growth, unpredictable climate change, declining agricultural productivity, an unstable labour force, and greater urbanization. The nutrient utilization efficiency of conventional fertilizers is pitifully poor. According to reports, between 40 and 70 percent of applied fertilizers' nitrogen, 80 to 90 percent of their phosphorus, and 50 to 90 percent of their potassium content are lost in the environment and do not reach the plant, resulting in huge monetary losses (Trenkel 2010; Saigusa 2000; Solanki et al. .2015) By 2050, when we must feed a population of over 9 billion people, these issues seem to be getting worse much faster. In a world of finite resources and an ever-increasing global population, agriculture has always been crucial as a source of food fiber (Brennan 2012). The nations that rely heavily on agriculture must embrace more sophisticated technologies, labor-saving techniques, and strategies to combat this dilemma. Nanotechnology is a potentially useful instrument that might usher in a new era of precise farming methods, making it a potential answer to these issues. Even in harsh areas, the use of nanotechnology in agriculture could lead to increased yields that are environmentally beneficial (Sugunan and Dutta 2008). Although NPs are currently being researched for their potential application in crop development, we may anticipate seeing them used frequently in farmers' fields in the near future. When diverse signals, like as heat, wetness, and other types of abiotic stress, are reacted to, the nano fertilizers release the nutrients in a controlled way. Nano fertilizers may control nutrient release, deliver the precise amount of nutrients that crops need in the right proportion, and increase crop yield while protecting the environment (De Rosa et al. 2010). According to Millan et al. (2008), NH_4^+ that has taken up residence in the zeolite's internal channels may be released gradually and freely. This enables the crop to gradually absorb the NH_4^+, which is evident in the crop producing more dry matter. Recent years have seen a significant increase in interest in using NPs on plants to manage agriculture (Nanotechnology in Agriculture and Food 2006; Torney et al. 2007; Khodakovskaya et al. 2009, 2012; Ashrafi et al. 2010; Serag et al. Razzaq et al. 2016; Husen and Siddiqi (2014); 2011b, 2012a). The genetic ramifications of these NP-induced positive changes have been confirmed through research on enhanced mRNA expression and protein level in spinach (Gao et al. 2008) by nano-TiO_2, generational transmission of fullerol through seeds in rice (Lin et al. 2009), and changes in gene expression at the plant and cellular levels in tomato and tobacco (Khodakovskaya et al. 2009, 2012; Villagarcia et al. 2012 According to Dwairi (1998), zeolite impregnated with urea can be utilized as slow-release fertilizer, allowing for the gradual release of nitrogen from nano zeolite. (2011), (2012), (2014), Razzaq et al. (2016), Husen and Siddiqi. Through research on improved mRNA expression and protein level in spinach (Gao et al. 2008) caused by nano-TiO_2, generational transmission, and genetic implications, these NP-induced beneficial alterations have been proven to have genetic implications. In comparison to ammonium sulphate, Perrin et al. (1998) showed that supplementing sandy soil with ammonium-loaded zeolite can increase N use efficiency while preserving sweet corn growth and reducing N leaching. The combination of zeolite with slow-release N fertilizers would boost the N efficiency, as Hernandez et al. (1994) also showed. According to Rahale (2010), the NUE was up to 45% higher with nano fertilizer than with control. Additionally, she stated that even 1176 hours later, nano zeolite continued to produce nitrate, with quantities ranging from 110 to 114 mmol L 1. In contrast to conventional fertilizer, which releases nitrogen slowly and steadily over a period of eight days, nano zeolite releases nitrogen over a period of more than 45 days. We are aware that under nutritional limitation, plants exude carbonaceous chemicals into the rhizosphere. These molecules can be used as environmental cues to develop innovative nano fertilizers (Sultan et al. 2009). By controlling the release of nutrients and preventing eutrophication and water resource contamination, novel nano fertilizer application has an advantage over conventional fertilizer application methods (Sekhon 2014; Naderi and Abedi 2012). The use of nano fertilizer increases the elements' use efficiency while also decreasing the toxicity produced by fertilizer overapplication in the soil and fertilizer split applications. Zinc oxide nanoparticles' beneficial impact on tomato plants provides a path for their future usage as a nano fertilizer. It has been noted that NPs in low concentrations have not shown any detrimental effects on plants, but rather are capable of triggering particular physiological and molecular responses. For instance, spinach can benefit from the addition of TiO_2 nanoparticles (0.25–4 percent), which can stimulate photosynthesis and nitrogen metabolism. This enhances plant development (Zheng et al. 2005; Klaine et al. 2008). Multiwalled carbon nanotubes (MWCNTs) were shown by (Khodakovskaya et al. 2009) to be effective at penetrating dense seed coats, promoting germination, and accelerating plant growth (Khodakovskaya et al. 2009, 2012). The application method and the media, however, have an impact on the effects of NPs.(Zhu et al).

Nano Urea

Nano-based controlled-release or slow-release fertilizers have great promise for increasing the effectiveness of nutrient utilization. Nanofertilizers may control nutrient release, deliver the precise amount of nutrients that crops need in the right proportion, and increase crop yield while protecting the environment (De Rosa et al. 2010). According to Millán et al. (2008), NH4+ that has taken up residence in the zeolite's internal channels may be released gradually and freely. This enables the crop to gradually absorb the NH4+, which is evident in the crop producing more dry matter. According to Dwairi (1998), urea-impregnated zeolite can be utilised as slow-release fertilizer, releasing nitrogen from nano zeolite gradually and steadily. "Perrin et al." (1998) showed that supplementing sandy soil with ammonium-loaded zeolite can decrease N leaching while preserving sweet corn growth and improving N use efficiency when compared to ammonium sulphate. The combination of zeolite with slow-release N fertilizers would boost the N efficiency, as Hernandez et al. (1994) also proved. According to Rahale (2010), nano fertilizer enhanced NUE by up to 45% over control. Additionally, she noted that even 1176 hours later, nano zeolite continued to produce nitrate, with quantities ranging from 110 to 114 mmol L 1. The results showed that nano zeolite released N slowly and steadily for more than 45 days, compared to only 8 days with conventional fertilizer. . It was found that the modified nanoparticles may effectively be used in parched soil to mitigate the serious issue of moisture retention. In addition to holding onto moisture, nano-based slow-release fertilizers may boost crop productivity by relocating nutrients in the rhizosphere (Raliya et al. 2013). An alternate method to increase the effectiveness of nitrogen use in crop production systems is to utilise nitrogen fertilizer supplemented with nanoporous zeolite (Manikandan and Subramanian 2014). When compared to control seedlings, Nair et al. found that rice seedlings grown in carbon nanomaterial-enriched media had better root development and shoot establishment (2012). In a fascinating investigation, Subramanian and Rahale (2009) tracked the nutrient release pattern of nano fertilizer formulations including nitrogen fertilizer. According to the data, nanoclay-based fertilizer formulations (zeolite and montmorillonite with a dimension of 30–40 nm) are able to release the nutrients for a longer period of time (>1000 h) than conventional fertilizers (1000 hrs).

Nanofertilizers based on copper

CuO NPs were moved from the roots to the shoots via the phloem and back again (Shankar et al. 2003). Maize and wheat were able to absorb particulate CuO NPs (Dimkpa et al. 2012, 2013; Wang et al. 2012a, b). In an agar growth medium, Cu NP uptake and translocation in wheat and mung bean (Vigna radiata) were assessed. The outcomes demonstrated that Cu NPs could pass through cell membranes and collect inside of cells. The bioaccumulated NPs in plant tissues and growth media were found to be significantly correlated. Additionally, it was found that mung bean was more sensitive than wheat to the toxicity of Cu NPs, perhaps as a result of variations in root anatomical structure (Lee et al. 2008; Rico et al. 2011 Compared to copper bulk particles, copper nanoparticles were more capable of being taken up by shoots (BPs). The total uptake into the shoots was, according to the findings, around three times higher for the NPs. Energy dispersive spectroscopy (EDS) analysis did not reveal specific elemental signals for Cu in either control samples or samples exposed to 500 mg/L NPs, and scanning transmission electron microscopy (STEM) images of radish (Raphanus sativus) shoot samples did not reveal any significant evidence of electron-dense deposits (Atha et al. 2012). Copper nanoparticles' ability to promote wheat development and yield was investigated by Hafeez et al. (2015). When Cu NPs (at 10, 20, 30, 40, and 50 ppm) were sprayed to soil in pots, the growth and yield were noticeably higher than the control. However, at 30 ppm Cu NPs, a considerable rise in the amount of chlorophyll, leaf area, number of spikes per pot, number of grains per spike, 100-grain weight, and grain yield was seen. The higher growth and yield in wheat caused by Cu NPs is concentration-dependent, according to the results, and more research is needed to determine the best dose to use and how to apply it in order to maximize wheat production.

Nanofertilizers based on zinc

Zinc (Zn) and zinc oxide (ZnO) are two of the metal- and metal oxideengineered nanomaterials that are frequently used on plants. According to Stella et al. (2010), zinc insufficiency is one of the most prevalent micronutrient deficiencies in soil and is the fourth most significant yield-limiting nutrient after nitrogen, phosphorus, and potassium. Due to its widespread use in consumer goods, it is likely that Zn or ZnO may reach air surroundings either by unintentional release or intentional application. This could also have a significant impact on a variety of creatures, especially plants, which are a vital component of all ecosystems (Dwivedi and Randhawa 1974). For the formation of auxins, pollen, fertilization, and chlorophyll, nanomaterials containing zinc are required. Zn is a micronutrient that guards plants against drought stress (Sharma et al. 2009). Seed germination rates may also be impacted by zinc and ZnO. For the species of Buck wheat (Fagopyrumesculentum), ZnO was found to have an impact on root germination (Sooyeon et al. 2013). Onion (Allium cepa) root length, genetic makeup, and metabolism were all significantly impacted by the ZnO nanoparticles. The growth of maize roots was stopped by soaking and incubating the seeds in a suspension of Zn/ZnO nanoparticles. According to many ideas, the toxicity of ZnO nanoparticles and Zn2+ is caused by either the stress or stimulus imposed by the ZnO nanoparticles' size, shape, and surface, or it is caused by the chemical toxicity based on chemical composition. The plant cell culture responses were impacted by both theories. The most crucial method of action may be internal efficiency, or Zn/ZnOutilization in tissues, depending on the plant species and the experimental settings, or Zn/Zn absorption, which is regarded as external efficiency (Dwivedi and Randhawa 1974). In order to prevent seedling growth, ZnO nanoparticles were purposefully allowed to infiltrate the root cells. In contrast to rye grass and maize, where seed germination was hindered by nanoscale zinc and ZnO, respectively, the seed germination and root growth investigation of zucchini seed in hydroponic solution containing ZnO nanoparticles showed no adverse response (Stampoulis et al. 2009). The uptake of ZnO nanoparticles caused damage to epidermal and cortical cells, as well as the potential to harm endodermal and vascular cells, which would restrict the growth of rye grass, as was demonstrated by electron microscopy (Lin and Xing 2007). The roots of the plants received the ZnO NPs, which equally distributed themselves throughout the tissues of the plants. However, not every crop may respond to ENPs in the same way. ZnO NPs, as opposed to CeO2 NPs, were discovered to be translocated into above-ground plant tissue, demonstrating that uptake and translocation are depending on NP type (Priestera et al. 2012). The ZnO NPs were ingested by the roots of the plant and distributed equally throughout its tissues. However, not every crop may respond to ENPs in the same way. ZnO NPs, as opposed to CeO2 NPs, were discovered to be translocated into above-ground plant tissue, demonstrating that uptake and translocation are depending on NP type (Priestera et al. 2012). ZnO NPs (8 nm) uptake and accumulation in soybean (Glycine max) seedlings were studied at concentrations between 500 and 4000 mg L1. In comparison to concentrations of 1000 mg L-1 and above, the absorption of Zn NPs by soybean seedlings was considerably higher at 500 mg L-1. This may be due to the fact that at lower concentrations (500 mg L-1), the NPs do not aggregate as much, whereas at higher concentrations (1000-4000 mg L-1), the development of agglomerates is predicted. The difficulty arises when large agglomerates try to get through the cell pore walls. According to the findings, this ultimately decreases ZnO NP uptake and accumulation (Lopez-Moreno et al. 2010a). Soybean plants grown hydroponically absorbed ZnO NPs as Zn2+ oxidation state. Later, theorised that ZnO NPs at the root surface changed into Zn2+ oxidation state (LopezMoreno et al. 2010a). Dimkpa et al. (2013) and Wang et al. (2013) both reported results that were comparable (2013a, b, c). According to Raliya and Tarafdar (2013), the rhizospheric microbial population, protein synthesis, chlorophyll content, and activity of the enzymes acid phosphatase, alkaline phosphatase, and phytase were all greatly enhanced by ZnO NPs. The addition of ZnO NPs to MS media resulted in proline production, enhanced superoxide dismutase (SOD), catalase (CAT), and peroxidase activity, and increased tolerance to biotic stress. Hernandez-Viezcas et al. (2011) investigated the results of 10 nm ZnO NPs at 500–4000 mg L1 concentrations on hydroponic cultures of velvet mesquite. Catalase and ascorbate peroxidase (APX) activity was measured specifically to assess the plant's response to NP-induced stress. While no signs of harmful effects, such as chlorosis, necrosis, stunting, or wilting, were seen even after 30 days of treatment, indicating a significant tolerance level toward ZnO NPs, the NPs were noted to increase the specific activity of CAT (in the root, stem, and leaves) and APX (only in the leaves). kumari et al. (2011) found that as ZnO NPs or ZnO bulk concentrations increased, higher values for the thiobarbituric acid reactive species (TBARS) were seen. The formation of TBARS, which compromises membrane permeability and is predicted to be one of the causes of the observed phytotoxicity, results from the conversion of fatty acids to toxic lipid peroxides during the formation and release of reactive oxygen species (ROS). This disruption of biological membranes facilitates the entry of and damage by NPs and metals. It has been discovered that ZnO NPs are associated with extremely vacuolated, compressed cortical cells as well as the contraction and partial mortality of the vascular cells (Lin and Xing 2008). 20 mg mL-1 zinc oxide nanoparticle solution recorded the highest growth and biomass production in an experiment with foliar spraying of various concentrations of ZnO NPs (0-100 mg L1) solution on tomato plants grown in pots (Panwar et al. 2012; De Rosa et al. 2013). The concentration of

ZnONPs has been shown in the majority of studies to affect plant growth. In soybean, root extension was recorded at 500 mg L-1, however higher amounts caused the roots to shorten. Even at greater concentrations (4,000 mg L-1; Lopez-Moreno et al. 2010), there was no influence on the germination of soybean seeds. On the growth of mung bean and chick pea plant seedlings, Mahajan et al. (2011) showed the impact of nano-ZnO particles (Cicerarietinum). ZnO NPs demonstrated a concentration-dependent pattern of growth in mung bean and chick pea seedlings. For mung bean and chickpea seedlings, the greatest growth was recorded at 20 ppm and 1 ppm, respectively; at higher concentrations, the growth was suppressed. According to Prasad et al. (2012), peanut seeds react differently to the treatment depending on the concentration of bulk ZnSO4 and nanoscale ZnO particles. Zinc content was estimated using post-harvest leaf and kernel samples, and the results were encouraging. ZnO NPs were more readily absorbed by plants than ZnSO4 in bulk. The results also showed that NPs had positive impacts on peanut plant growth, development, and yield at lower dosages (1000 ppm), while at higher concentrations (2000 ppm), ZnO NPs had negative effects similar to those of the bulk nutrients. ZnO-treated plants had a 34 percent higher pod output per plant than bulk ZnSO4 that had been chelated. The peanut (Arachis hypogea) seeds treated with nanoscale ZnO were observed to absorb Zn using scanning electron microscopy and energy dispersive analysis of X-rays (SEM-EDAX). The peanut embryo was cut up into tiny pieces for SEM analysis. Despite the expectedly low Zn content in peanut seeds being seen in EDAX spectra, EDAX images showed that substantial Zn accumulation was also seen in the areas of the seeds treated with nanoscale ZnO. When 10 ppm ZnO NPs were foliar sprayed on the leaf of a 14-day-old plant, Raliya and Tarafdar (2013) showed similar results on shoot length, root length, root area, and plant biomass in cluster bean (Cymopsistetragonoloba). The use of ZnO NPs significantly increased the shoot length (31.5%), root length (66.3%), root area (73.5%), and plant biomass (27.1%) of 6-week-old plants as compared to the control. It was investigated how ZnO NPs affected onion growth, flowering, and seed production (Laware and Raskar 2014). The ZnO NPs were sprayed three times at intervals of 15 days on six-month-old onion bulbs that had been divided into half. The concentrations used were 0, 10, 20, 30, and 40 g ml1. Upon the time of flowering, the growth parameters—plant height and leaf count—were measured; at harvest, the seed yield parameters—number of fruited with seeds per umbel, amount of seeds produced per umbel, and weight of 1,000 seeds—were calculated. Tests on germination and early seedling growth were performed on seed samples taken from treated and control plants. According to the findings, plants treated with ZnO NPs at concentrations of 20 and 30 g ml1 grew better and flowered 12 to 14 days earlier than controls. Compared to control plants, treated plants greatly outperformed them in terms of seeded fruits per umbel, seed weight per umbel, and 1000-seed weight. It was established that improved ultimate yields were the result of high-quality seed working in conjunction with all other inputs (size, number, etc.). These findings shown that ZnO NPs can yield high-quality, viable seeds while shortening the onion flowering period by 12–14 days. The fundamental function of ZnO in maintaining and safeguarding the structural stability of cell membranes, as well as its participation in protein synthesis, membrane function, cell elongation, and tolerance to various environmental stresses, may be related to the increase in vegetative growth in onions (Welch et al. 1982). (Cakmak 2000). In a different study, Kisan et al. (2015) investigated the impact of nano-ZnO on the spinach leaf's physical and nutritional qualities. After 14 days after seeding, ZnO NPs in varied concentrations (0, 100, 500, and 1000 ppm) were sprayed on the spinach plants. The physical characteristics of the leaves, such as their length, width, and surface area, as well as their nutritional characteristics, such as their protein, carbohydrate, fat, and dietary fibre contents, were noted at the time of maturity (45–50 days). Increases in the leaf length, width, surface area, and colour of spinach leaves were seen when ZnO NP concentrations of 500 and 1000 ppm were sprayed. When compared to control spinach leaf samples, plants treated with ZnO NPs at the concentrations of 500 and 1000 ppm showed enhanced amounts of protein and dietary fibre. It has been suggested that using nano-zinc oxide as a biofortification agent could boost the protein and dietary fibre content of spinach leaves, hence lowering malnutrition. Zinc oxide nanoparticles' beneficial effects on tomato plants suggest that they could one day be used as a nanofertilizer. 20 mg mL-1 zinc oxide nanoparticle solution recorded the highest growth and biomass production in an experiment with foliar spraying of various concentrations of ZnO NPs (0-100 mg L1) solution on tomato plants grown in pots (Panwar et al. 2012; De Rosa et al. 2013). Energy dispersive spectroscopy (EDS) analysis of radish (Raphanus sativus) shoot samples did not reveal any distinctive elemental signals for Cu in either control samples or samples exposed to 500 mg/L NPs. Microscopy (STEM) images of radish (Raphanus sativus) shoot samples did not reveal any significant evidence of electron-dense deposits (Atha et al. 2012). The potential for copper nanoparticles (NPs) to boost wheat growth and yield was investigated by Hafeez et al. in 2015. In comparison to the control, the growth and yield greatly enhanced when Cu Shyla and Natarajan have reported on the impact of nanoparticles on germination and seed quality improvement (2014). Because nanoscale zinc has a stronger precursor activity in the formation of auxin, ZnO NPs may have favourable impacts on seed germination. Zinc is also necessary for enzymes that catalyse several processes and for plant growth. When ZnO NPs (10 mg L-1) were foliar sprayed onto the leaf of a 14-day-old plant, Raliya and Tarafdar (2013) observed a considerable improvement in the gum content and viscosity of cluster bean seeds during crop harvest. Improved growth metrics and gum content may be the result of NPs adhering to plant surfaces and being absorbed by plants through their own natural nano- or microscale apertures.

IFFCO develops and makes nano-fertilizers iffco develops and makes nano-fertilizers

IFFCO investigated cutting-edge methods to create nano-N (urea), nano Zn, and nano Cu through nanotechnology to boost NUE for raising crop yields, decrease the consumption of bulk fertilizer, and increase farmer profitability at decreased environmental cost. The Nano Biotechnology Research Center (NBRC) was founded by IFFCO on November 3, 2019, in Kalol, Gandhinagar, Gujarat, to meet these goals. Three products—nano nitrogen, nano zinc, and nano copper—that NBRC has independently produced and patented are nano nitrogen. The required particle characteristics of these nanoscale nutrients include form, size, purity, content, concentration, stability, polydispersity index (PDIvalue), pH, and crystal phase. They satisfy the nutritional needs of plants as fertilizer because they are bio-available and within the scientific application range (10 to 80 ppm) for the appropriate content in plants.

Nanourea by IFFCO

A innovative solution to weaning farmers off of urea is nano nitrogen, which is based on nanotechnology principles. To efficiently meet crops' needs for nitrogen, it is necessary to take use of nitrogen particles' nanoscale advantages. Reduces urealosses, improves nutrient uptake effectiveness, and tackles environmental problems of soil, air, and water pollution through precise and targeted administration of nitrogen through foliar spray of nano nitrogen. Better farm economics are produced as a result of better crop yield with less nitrogen applied per unit area. Spraying nanonitrogen at a rate of 2-4 mL per litre of water during key periods of crop growth stimulates a response from the crop, satisfies its nutritional needs, and also increases nutrient availability in the rhizosphere. Nano N fertilizer, which has a size of about 100 nm, is quickly absorbed when sprayed on leaves and enters through stomata. Through phloem translocation, it reaches other plant parts and is metabolically absorbed as proteins, amino acids, etc. to meet the needs of the plant. Compared to a 1 mm urea prill, nanoscale nitrogen particles (30–50 nm) in nano urea have 10,000 times greater surface area (55,000 nitrogen particles over 1 mm urea prill). A nano nitrogen particle with a 20 nm pore size can easily pass through a cell wall and up to the plasma membrane. Stomatal holes can be penetrated by large particles (30 to 50 nm). They are also transferred to other plant sections by phloem cells, passing through plasmodesmata (40 nm in diameter). They are processed within the plant cell and can bind to carrier proteins via aquaporin, ion channels, and endocytosis. Therefore, introducing a nanoscale particle by foliar application, such as nanonitrogen, results in more effective absorption and penetration of nitrogen in seed development.

Nano Zinc by IFFCO

Zinc is fundamentally necessary for the healthy growth and development of plants, animals, and humans. The diet of humans must include zinc, which is either directly or indirectly derived from plants. There is a significant zinc deficit in Indian soils. Zinc (Zn) and zinc oxide (ZnO) are two of the metal and metal oxide manmade nanomaterials that are frequently used on plants.

Nano Zn and Nano Cu from IFFCO

Plants obtain the Zn and Cu they need from the soil, but because micronutrient shortages are becoming more common, bulk fertilizers are being used to supply crops with these elements. Due of their poor soil use efficiency, current fertilizer alternatives are ineffective. Nano zinc and nano copper's main objectives are to replace their conventional fertilizer analogues, which have use efficiencies between 2 and 5 percent, boost agricultural productivity, and improve crop quality through agronomic fortification. Additionally, nano zinc promotes superior physiological growth, increases plant uptake of P, and consistency in fruit size and shape. Similar to how micro copper strengthens plants' natural defences against harmful bacterial and fungal diseases, which influences their general growth and development.Due to their small size, nano zinc and nano copper can be readily absorbed by plants either directly or through stomatal holes when sprayed on the leaves. Following entry through the leaves, they are transferred to various plant sections through phloem translocation and metabolically absorbed in accordance with the needs of the plant.

Nano Copper IFFCO

One of the eight essential minerals for plants, copper is also necessary for good seed formation and plant metabolism. Increased susceptibility to harmful bacterial and fungal infections brought on by copper deficiency can result in considerable output losses. Cu nanoparticles couldtransverse the cell membrane and collect inside the cells. There is a clear connection between growing conditions and the bio accumulated NPs in plant tissues. For best results, nano zinc or nano copper are sprayed twice at the plant's most crucial growth stages, first during the plant's initial growth stages and then again at the pre-flowering stage, at a rate of 2-4 mL per tree of water. If necessary, nano zinc and nano copper can be combined while spraying; otherwise, they can be utilised independently. For various types of crops, including legumes, grains, oilseeds, vegetables, and fruit, IFFCO nano zinc and nano copper can be used.crossing the cell membrane, then gathering inside the cells. Growing circumstances and the bio-accumulated NPs in plant tissues are clearly related. To achieve the greatest effects, nano zinc or nano copper should be applied twice, once during the plant's early growth phases and once more during the pre-flowering period, at a rate of 2-4 mL per tree of water, during the most important growth stages of the plant. Nano zinc and nano copper can be used separately or in combination during spraying, depending on the situation. IFFCO nano zinc and nano copper are suitable for use with a variety of crops, including grains, legumes, oilseeds, vegetables, and fruit.

IFFCO's potential for nano urea, nano zinc, and nano copper

The OECD testing guidelines (TGs) and the Department of Biotechnology of the Government of India's "Guidelines for Testing of Nano Agri Inputs (NAIPs) and Food Products" are in line with the IFFCO nano urea, nano zinc, and nano copper. The harvested products of crops treated with IFFCO's nano urea, nano zinc, and nano copper have been determined to be safe for food. These can be used without endangering the environment or the user. These also offer incremental advantages such cost effectiveness and versatility for use in sheltered cultivation, dry land agriculture, and rainfed agriculture. Additionally, they work well with the majority of biostimulants, specialist fertilizers, and agrochemicals. Independently,

Conclusion:

The mainstay of the Indian economy is agriculture, which uses both renewable and non-renewable resources to feed the nation's population. The need to reinvent agriculture through the use of cutting-edge technologies like nano-fertilizers is driven by rising consumer awareness of food traceability, environmentally friendly agri-inputs, and sustainable farm operations.As a leading cause of environmental pollution, nitrogen pollution (NO3-, NH4+, and N2O) is now being targeted internationally for gradual decrease. It is a part of the Paris Climate Change Agreement and UN Sustainable Development Goals (SDGs). In order to maintain a healthy ecosystem and soil-crop-atmospheric biodiversity throughout time, excessive nitrogen application in agriculture must be reduced gradually. The overall crop economy and environmental resilience are improved when excessive fertilizer use is reduced.In addition to agriculture, nanotechnology has found widespread use in other industries as a creative solution. Worldwide, more than 1200 commercial goods based on nanotechnology have found a place as products and their variations in the consumer and industrial space. In terms of size, shape, quantity, and effectiveness, nano goods clearly have an advantage. In terms of environmental sustainability and resource preservation, they can overcome scale and scope-related constraints. Nanoagri inputs allow for the targeted, stage-by-stage, and slow release delivery of nutrients to crops without affecting the agroecology.Nano-fertilizers are novel because of their distinctive size, makeup, and characteristics. Due to the activation of alternate routes and enzymes within the plant system, an increase in root biomass, and a rhizospheric microbial population, their application increases the bioavailability of nutrients. In order to be successfully integrated into the package of practises (POPs) of states and as a useful part of the 4 R approach, nano-fertilizer administration can be further streamlined in accordance with focus crop nutrient uptake and removal research throughout time. This context should be considered while evaluating nano goods, particularly IFFCO nano urea.Therefore, nano-fertilizers should be considered as a whole as a solution to the problems that contemporary intensive agriculture is facing. The acceptance of nano-fertilizers as a "educated option" to solve enduring constraints affecting the sustainability and profitability of our agriculture is long overdue.

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