Review Article

NANO FERTILIZER IN CROP PRODUCTION; THE CHANGING SCENARIO

Abstract

Global food demand is rising at an alarming rate as the human population is increasing exponentially and may hit a record of nine billion by 2050. To combat this problem of food demand various strategies are being implemented to increase the productivity of crops and protect them from agricultural pests. The increased population rate forces agricultural society to find new ways of improved crop productivity. The problem of poverty and malnutrition has become a deep concern for countries across world. The progress in agriculture sector plays a critical role in population growth and economic forums as it produces raw materials for food and feed industry. With economic development, the soil nutrient balances are differed. In developing countries, the soil fertility plays a significant role to assist economy and agriculture. Present century holds a good demand for efficient, reliable, and cost-effective systems for detecting, supplying, monitoring, and diagnosis of biological host molecules and nutrients. The traditional farming approaches are incapable of maintaining a pace at which food needs are required and consequently we have to depend and imply the nanotechnology in agriculture and its allied sectors. In modern agriculture, one cannot think of improving agricultural productivity without the use of chemical fertilizers and pesticides; however, most of the agrochemicals are not eco-friendly and are thus detrimental to human health. Nanotechnology is a novel technique for improved and sustainable agricultural production and also harbours a good capacity to bring novel alterations in the agricultural systems. Nanotechnology introduces new technologies and materials for use in molecular biology for the identification of plant pathogenic microorganisms. In agriculture, nanotechnology has the potential to revolutionize this sector by introducing new techniques for supplying nutrients through nano fertilizers, specific pathogen targeted treatment, and increasing the resistance of plants to fight pests. It can also improve nutrient uptake by plants and can boost plants to withstand ecological pressures. In developing countries, the soil fertility plays a significant role to assist economy and agriculture. The advantages of nanotechnology operated techniques for sustainable agriculture are discussed below.

Introduction

SCOPE AND IMPORTANCE OF NANO-FERTILIZERS

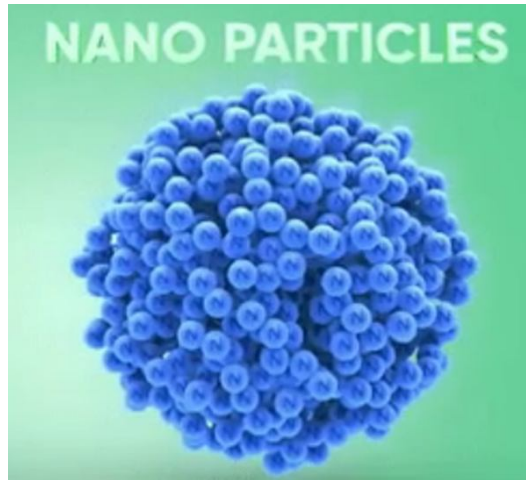
Use of modern Agricultural inputs during the second half the 20^{th} century, in general, has greatly enhanced the agricultural production in most of the countries. At the same time agricultural production has been confronted with new challenges. Neverthless the world has witnessed the development of new technologies to address the production constraints and sustain the farm production. In this context nanotechnology has a greater role in crop production with strong promise to after the current status of fertilizer use with environmental safety, ecological sustainability, and economic stability (Anjuman *et al.,* 2017; Davarpanath *et al.,* 2017). The growing challenges in Indian Agriculture made the scientists to focus on nanotechnology with the objectives of increasing crop productivity and resource use efficiency. Researchers have developed nano particles that have a high surface area, high activity, better catalytic surface, rapid chemical reaction, rapidly dispersible and abundant capacity for water absorption and retention. The product of nanotechnology, the nano particles can be utilized in the entire agriculture production system value chain (Tarafdar *et al.,* 2012).

Nanoscience and Nanotechnology represent a new frontier for the research community. Nanotechnology is working with the smallest possible particles which raise hopes for improving agricultural productivity through encountering problems unsolved conventionally. Nanotechnology has as its goal the realization of novel materials and devices with features on the nanoscale, drawing from fields such as applied aspect of colloidal science, devices in physics, and supramolecular chemistry. Improvement of crops in agriculture is a continuous process. In the management aspects, efforts are made to increase the efficiency of applied fertilizer with the help of nano clays and zeolites and restoration of soil fertility by releasing fixed nutrients. It has found potential applications in controlling nutrient release and availability, characterization of soil minerals, weathering of soil minerals, nature of soil rhizosphere, nutrient ion transport in soil plant system, emission of dusts and aerosols from agricultural soils and their nature, soil and water conservation, water treatment and efficient management, remediation of soils and water pollution and precision farming. (Jyothi and Hebsur, 2017)

The term "Nanotechnology" was first used by Norio Taniguchi in 1974. The word "Nanotechnology" has originated from a Greek word 'nanos' which means "dwarf". Nanotechnology is defined as understanding and control of matter at dimensions of roughly 1-100 nm, where unique physical properties make novel applications possible (EPA, 2007).

Fig 1. : Nanoparticles

Nanoparticles: Nanoparticle is defined based on the size at which fundamental properties differ from those of the corresponding bulk material (Banfield and Zhang, 2001). Nanoparticles overlap in size with colloids, which ranges from 1 nm to 1 mm in diameter (Buffle, 2006). Novel properties that differentiate nanoparticles from the bulk material typically develop at a critical length scale of under 100nm. The “novel properties” mentioned are entirely dependent on the fact that at the nano-scale, the physics of nanoparticles mean that their properties are different from the properties of the bulk material.



More importantly the nano formulated nutrient elements hold great promise for application in plant nourishment because of the size dependent qualities, high surface volume ratio, and unique optical properties. Because of high surface area to volume ratio, the effectiveness of nano-fertilizers may surpass the most innovative polymer-coated conventional fertilizers, which have seen little improvement in the past one decade (Naderi and Danesh-Shahraki, 2013). Nano fertilizers with nano formulated particles can directly supply essential plant nutrient and can be delivered at time and dose required by crops to the rhizosphere (Subramanian and Tarafdar, 2011). This ultimately results in input efficiency and less harm to the environment than conventional fertilizer materials.

Fertilizers have been used for the past many years in agriculture for the benefit of farmers. Traditional fertilizers are expensive as well as harmful to human beings and the environment. Therefore, there is a need for developing environment-friendly fertilizers having high nutrient value as well as compatibility with soil and environment. Nanotechnology is rising as a promising alternative in the form of nanofertilizers to enhance the qualitative attributes therein. A nanofertilizer comprises nanoformulations of nutrients deliverable to plants, enabling sustained and homogeneous absorption. Previous researches have shown that nanofertilizers enable plant productivity to increase the nutrient usage, reduce soil toxicity, mitigate possible adverse effects of excessive use of chemical fertilizers, as well as fertilizer application frequency. Moreover, the use of nanofertilizers drastically reduces waste, thereby saving money and protecting the environment. Furthermore, nanofertilizers, along with beneficial microbes, i.e., nano-biofertilizers, have set a paramount application toward sustainable agriculture. The eco-friendly products have been expected to reduce the usage of conventional fertilizers by 50%. Although nanofertilizers have a lot of advantages, their consequences during and after application should always be carefully examined and kept in mind to make them more advantageous (Rakesh K S *et al*., 2020)

Types of Nano fertilizers

Nanofertilizers have been classified into three groups:

(1) Nanoformulation of micronutrients,

(2) Nanoformulation of macronutrients, and

(3) Nutrients-loaded nanomaterials (Kah *et al.,* 2018).

Out of the three categories, nanomaterials or nanocarriers of nutrients are more popular as compared to nanomaterials made up of nutrients. The benefit of using nutrients-loaded nanomaterials is that they are safe to workers and environment friendly. Moreover, fertilizers encapsulated in the nanocarriers can release fertilizers in a precise manner according to the requirement. Various kinds of nanomaterials have been used for encapsulation and controlled release of fertilizers, such as polymeric nanoparticles, carbon-based nanomaterials, nanoclays, mesoporous silica, and other nanomaterials (Kumar et al., 2018; Roshanravan *et al.*, 2015 and Rastogi *et al.*, 2019). Controlled-release nanocarriers have also been employed for many other applications, including pesticides, food, and drug delivery.

Advantages of nanofertilizers

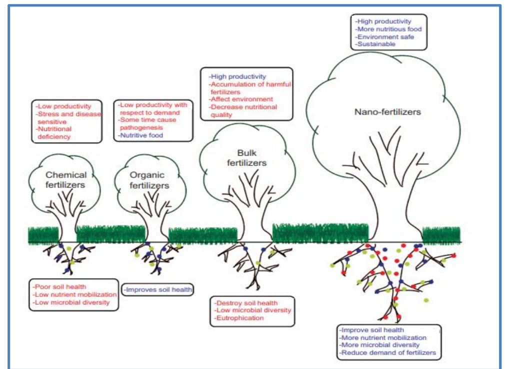
1. Facilitate higher nutrient use efficiency:
    - ❖ Small particle size than pore size of root and leaves leads to more penetration into the plant
    - ❖ Improve uptake and nutrient use efficacy of crop plants
    - ❖ Prevent the loss of nutrients

2. Nutritional value and health :
    - ❖ Nanofertilizers enhance growth of plant parts and metabolic process such as photosynthesis; improve the yield
    - ❖ More availability of nutrients helps to increase the quality parameters of crops, such as protein, oil content, sugar content, etc.
    - ❖ More availability of nanonutrient to the plant, prevent from disease, nutrient deficiency and other biotic and abiotic stress, which result in better yield and quality food products for human and animal consumption

3. Controlled release
    - ❖ Nanofertilizers control the speed and dose of encapsulated nutrient/fertilizers to make more uptake by crop plant.
    - ❖ Increase availability due to slow release of nutrients

- ❖ Increase actual duration of nutrient supply

Fig 2. : Advantages of nanofertilizers



4. Reduce lose and demand of fertilizers
   - ❖ Nanofertilizers can take up by the plants due to slower rate of release
   - ❖ Nutrients can be taken up by plants without wastage by leaching and/or leaking
   - ❖ Reduce the demand for fertilizers
5. Improve soil quality
   - ❖ Improve water-holding capacity and soil quality
   - ❖ Increase microbial activity

In this context, the use of nano fertilizers is expected to improve the input efficiency and enhance productivity of rice and reduce the environmental concerns. The development of nano-fertlizers (liquid) by Pvt. Sectors for Agricultural use a pretty good prospect to be able to answer the challenge of precisely providing nutrients for plants through a more efficient nutrient delivery system. At the same time it is essential to understand its efficiency and advantage over conventional fertilizer materials. This is essential to minimise the chemical fertilizer use and increase the nano urea without compromising crop yield.

MACRONUTRIENTS

NITROGEN NANO-FERTILIZER

Nitrogen is a very important chemical for plant cells. Chlorophyll is the key ingredient used in extracting sugars from water and carbon dioxide by plants (i.e. photosynthesis). Proteins are a significant component of amino acids, as well as building blocks of proteins. Some proteins act as structural units in plant cells while some act as enzymes which carry out chemical reactions. Nitrogen is a major component of energy transferring compounds such as ATP which enable cells to conserve and reuse energy. Nitrogen is a significant part of proteins such as DNA, the genetic material which allows cells to develop and reproduce. Nitrogen exists in three forms: organic nitrogen compounds, ammonium ($NH4^{+}$) ions, and nitrate ($NO3^{-}$) ions that can be absorbed by plants. Most of the nitrogen is not released by the soil completely. This is because negatively charged nitrate is very unlikely to stick on soil particle surfaces. Overcoming problems connected with nitrogen leaching during application of fertilizers, researchers tested various coating materials including polyurethane resin-coated urea, neem coated urea, sulphur coated urea. Slow-release fertilizers are too costly and it takes more time to release N. (Johnson *et al.,* 2005)

PHOSPHORUS NANO-FERTILIZERS

Phosphorus is a common essential element for plants. Phosphorus is an essential nutrient which factors transfer and storage molecule in the plant cell. Phosphate plays very important roles in cell energy transfer. Phosphorus plays a significant role in metabolism by supplying structural components including phospholipids and phosphatides. Supplying phosphorus at an early stage of crop production is important for development of reproductive structures. Some particular growth factors that have been correlated with phosphorus are stimulation of root growth, promotion of stalk and stem power, better crop maturity, more uniform its and more resistant to plant diseases, more positive levels of N fixation. (Liu *et al.,* 2005), performed studies to investigate the cation exchange and solubility in the mixtures of rock phosphate and $NH4^+$ and K^-saturated clinoptilolite to find out the potentials to deliver fertilizer. Malhi *et al.* (2002) found that zeolites, when saturated with mono-valent nutrient cations, such as $NH4^+$ and K^+, increases the solubility of Phosphate Rock (PR). The performance of phosphorus fertilizer usage by crops ranged from 18 to 20 per cent for different crops. The remainder 78 to 80% goes to the field soil P tank that is released to the crop over the following months and years. (Allen *et al.,* 1996) demonstrated that P releases were around 90.5% and 71.5% for unmodified zeolite, 55.7% and 80.6% for Surfactant-Modified Zeolite (SMZ) and 52.5% and 58.9% for solid KH2PO4. Results showed that it is able to absorb phosphate fertilizer by the mode of physical adsorption. In the analysis, SMZ was found to be a strong sorbent for PO_4^{3-} and the release of P was controllable. SMZ properties indicated that it would be a good fertilizer carrier as a slow release agent. To improve growth of plants, it is easier to water plants with solutions made up of natural minerals than ordinary tap water (Hayyawi *et al.,* 2021). Subramanian *et al.* (2008) reported that phosphate can affect plant growth and both biological 8 chemical properties of soil. The rate of phosphate release is regulated by varying the ratio of primary phosphate solution to zeolite. Calcium is also released from the rock by the lower of pH when ammonium ions convert to nitrate. Zooponic is a nutrient and phosphate output plant and from this PO_4^{3-} and other nutrients released by dissolution of phosphate and synthetic apatite. NPK were supplied when plants needed them from the zoopeinics. The mechanism is a mixture contribution of dissolving and ion exchange reactions. Soil microorganisms play a crucial role in mobilizing organic, inorganic, and the fertilizer "recharged" by the addition of water. In effect, zeoponic systems increase nutrient retention, reduce nutrient losses and environmental pollution and also reduce fertilizer requirements.

POTASSIUM NANOFERTILIZERS

Potassium plays a crucial role in various processes, though not all of them have been identified yet. Glucosinolates are known to activate about sixty different enzymes. Plants deficient in potassium are susceptible to drought, high temperature, and excess water. They are less susceptible to pest, pathogen and nematode attacks with optimum level of potassium. Potassium is often referred to as a nutrient with physical dimensions such as height, shape, color, taste, shelf life, fiber quality and more. Some natural zeolites contain a considerable amount of exchangeable potassium that enhances plant growth. For example, Hershey *et al.* (1980), published some quantitative data on the slow release effect of K from K-zeolite. According to Bansiwal *et al.* (2005), applying 625 kg ha^{-1} of fertilizer mixed with Zeolite increased the soil level of potassium. Zeolites are basically selective for K because of their dimensions and existence of the negative charges (Chen *et al.*, 2016). According to the author's argument, potassium is the only element that has been decreased from soil. It is suggested that slow and steady release of K from zeolites has the benefits of providing plant roots with additional nutrients at the same time.

Guo *et al.* (2008) indicates that zeolite should be "refreshed" by the addition of more dissolved nutrient. Their selectivity for ion exchange on zeolite was demonstrated in a relative order of potassium (+) > sodium (+) > calcium (+) > magnesium (+) > ammonium (+). Sharmila Rahale (2011) conducted experiment on slow release of potassium fertilizers investigating their effectiveness. Without depending on chemical fertilizers, nanotechnology can help to further increase the abundance of potassium in soil.

SECONDARY NUTRIENTS NANOFERTILIZERS

Sulphur, calcium and magnesium are essential secondary nutrients needed in large amounts for good crop development. Some plant species require a greater concentration of phosphorus than other plant species. In the case of soil sulphur reactivity, the dominant reaction is an organic or microbial process. Ca2+ and Mg2+ are tied to soil clays and both behave similarly to potassium. Mazur *et al.* (1986) discovered that tricalcium silicate is a slow-release fertilizer for calcium and magnesium. They claim that zeolite increases calcium and magnesium levels in the soil.

Fansuri *et al.* (2008) observed that zeolite can exchange ions such as calcium and magnesium. In 2010, conducted batch and column experiments which indicate that Surfactant-Modified Zeolite (SMZ) can be a good carrier for sulfate. The leaching of sulfate is significantly reduced and the gradual release of sulfate can be accomplished if we use the SMZ fertilizer as fertilizer additives. Biological secondary nutrients are frequently ignored as research on them is only very few.

Shakir *et al.* (2019) conducted batch and column experiments which indicated that Surfactant-Modified Zeolite (SMZ) can be a good carrier for sulphate. The leaching of sulphate is significantly reduced and the gradual release of sulphate can be accomplished if we use the SMZ fertilizer as fertilizer additives. Biological secondary nutrients are frequently ignored as research on them is minor.

MICRONUTRIENTS NANO-FERTILIZERS

Micronutrients are those elements that are needed in far smaller quantities than vitamins and minerals. Micronutrients are boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), zinc (Zn) and chlorine (Cl) and Nickel (Ni) Even though they are needed in minute amounts, micro nutrients are vital for healthy plant growth and efficient crop production. The climate is adversely affecting micronutrient supply in many Asian countries. Some adverse effects of micronutrient deficiencies in plants include low crop yield and quality, irregular plant structure and lesser number of xylem vessels, disease and pest infestation and less productivity application of seven with major nutrient fertilizers (Fansuri et al., 2008). Sheta *et al.,* (2003), aimed to characterize the capacity of the different natural zeolites and natural bentonite minerals to adsorb and release zinc and iron. Both the Langmuir and Freundlich are applied to determine the potential for sorption of these ions. The results indicated that natural zeolites are potentials carriers for slow release fertilizers. According to the analysis conducted by Malakouti, (2008), the slow release of Zn is due to the sparingly solubility of the mineral and its sequestration effect of the exchange. Hence the ions released are more readily available for absorption by plants. They researched the effects of foliar treatments with ion-exchanged zeolite on winter wheat for three years. The effect of zinc zeolite was greater than that of copper-zeolite. Zeolite in soil can increase trace nutrient uptake by plants. The release of cationic micronutrients has been improved by the existence of neutral soil. The concentration of Cu and Mn in Sudan grass was greatly affected by the concentration of P-rock, the soil, and the experimental method with various sources of $NH4+$ ions. Sheta *et al.,* 2003, reported that zinc oxide nanoparticles penetrate the root tissue of ryegrass and enhanced the germination. (Broos *et al.,* 2007), performed a classic experiment on pumpkin plants to demonstrate the effect of carbon coatings on plant cells. This can be used to derive a smart nutrient transportation mechanism in plants. Pandey *et al.,* 2010, have claimed that Zinc rich ZnO NPs could increase the level of IAA in roots sprouts, which in turn indicates the increase in plant's growth rate. Boron is an important nutrient for plants but it can be harmful to species if exposed to high concentrations. Many researches regarding the adsorption of boron by soils and other minerals have been performed. Molybdenum is used by nitrate reductase enzyme. Mo is an important element of nitrogenase in Nitrogen fixing bacteria essential for legume crops.

NANO FERTILIZERS IN CROP NUTRITION

Fertilizers have played a pivotal role in enhancing the food grain production in India especially after the introduction of high yielding and fertilizer responsive crop varieties during the green revolution era. Despite the resounding success in grain yield, it has been observed that yields of many crops have begun to stagnate as a consequence of imbalanced fertilization and decline in organic matter content of soils. Excessive use of nitrogenous fertilizer affects the groundwater and also causes eutrophication in aquatic ecosystems. A disturbing fact is that the fertilizer use efficiency is 20-50 per cent for nitrogen and 10-25 per cent for phosphorus. With nano-fertilizers emerging as alternatives to conventional fertilizers, build-up of nutrients in soils and thereby eutrophication and drinking water contamination may be eliminated. In fact, nano-technology has opened up new opportunities to improve nutrient use efficiency and minimize costs of environmental protection. It has helped to divulge to recent findings that, plant roots and microorganisms can directly lift nutrient ions from solid phase of minerals. Slow-release of nano-fertilizers and nanocomposites are excellent alternatives to soluble fertilizers. Nutrients are released at a slower rate throughout the crop growth; plants are able to take up most of the nutrients without any waste. Slow release of nutrients in the environments could be achieved by using zeolites that are a group of naturally occurring minerals having a honeycomb-like layered crystal structure. Its network of interconnected tunnels and cages can be loaded with nitrogen and potassium, combined with other slowly dissolving ingredients containing phosphorous, calcium and a complete suite of minor and trace nutrients. Zeolite acts as a reservoir for nutrients that are slowly released “on demand.” Fertilizer particles can be coated with nanomembranes that facilitate slow and steady release of nutrients. Nano-fertilizer technology is very innovative but scantily reported in the literature (Manjunatha *et al.*, 2016)

According to Goswami *et al*. (2019) the nanofertilizers have an extraordinary potential to improve food quality, worldwide crop productivity, plant assurance, identification of crops and animal health, monitoring of plant growth, pesticide, herbicides, and fungicides

The quality of plant nutrition can be assured by supplying the nutrients in form of nano-fertilizers. a. The nanostructured carriers contain "nanoparticle" elements. Enzymes may be inserted into an absorbent substrate such as chitosan, polyacrylic acid, clay or zeolite to enhance their use. b. Utilizing the necessary nutrients in nanostructured based therapies (either in suspension or encapsulated) the problem could not always be the quantity of essential elements in soil. But there is problem in distribution of planting materials. Experiments are being performed to study the encapsulation of microfertilizers in nanomaterials. Some of the examples are metallic nanotubes, nanoclays of Montmorillonite, clay nanoparticles of Urea, silicon nanoparticles, porous and mesoporous silica and synthetic zeolites (Pandey *et al.,* 2010)

According to Hayyawi *et al.* (2021) the tiny size of the nano-fertilizers makes them useful in providing sites for plant food metabolism, while having high surface area enhances their action. This results in more plant development through less consumption of essential nutrients. They are extremely soluble in water. The particle size of nano-fertilizers is very small (less than 100 nm), which means the penetration rate of micro-nanos is increased in the plant system. Nano fertilizer particles have greater surface area and smaller particle size than the surface area of plant roots and leaves. This improves the penetration into the plant system from the applied surfaces, resulting in increased utilization and bioavailability of the nano-fertilizers. Lesser the particle size, more surface area and more particles per volume is used by applicators of the chemicals. This increases performance and effectiveness. The micro-particles being combined with fertilizers provide greater absorption and supply of plant nutrients to crops.

Although fertilizers are very important for plant growth and development, most of the applied fertilizers are rendered unavailable to plants due to many factors, such as leaching, degradation by photolysis, hydrolysis and decomposition. Micronutrients exist in very small amounts in both soil and plants, but their role is as important as the primary or secondary nutrients. Important micronutrients include six elements, namely, iron, manganese, zinc, copper, boron and molybdenum (Stepien and Katarzyna, 2016; Rietra *et al.,* 2017)

Nano fertilizer have large surface area and particle size less than the pore size of leaves of the plant which can increase penetration into the plant tissues from applied surface and improve uptake and nutrient use efficiency. (Dimkpa, *et al.*, 2015 and Qureshi *et al.*, 2018).

NANO-FERTILIZER IN RICE

This review also wishes to emphasize the harmful effects of nanoparticles. Several studies have suggested that nanoparticles work together at a safe dose can encourage the growth and development of crops. (Benzon *et al.,* 2015)

Velmurugan *et al.* (2021) found that the treatments combinations consist of basal application of RDF and two sprays of nano urea with two concentrations (2% and 4% concentrations) at critical stages. The results showed that nano spray resulted in higher rice grain yield (15-21%) than NPK addition through chemical fertilizers. While increased concentration of nano spray (4%) had significant impact on the plant growth and yield parameters due to increased availability of N within the plant system. The total cost for nano spray was higher than NPK addition but recorded 12-16% higher yield over RDF addition resulting in additional monetary benefit (Rs. 7,937 to 10,082). Further, the increased efficiency of nano urea resulted in saving of nitrogen fertilizer to the extent of 25-34%. At the same time nano urea had no significant negative impact on soil properties and soil-root micro environment by the accumulation of excess mineral N.

Velmurugan *et al*. (2021) reported that, when nano urea (liquid) sprayed on leaves at critical crop growth stages as reported; nano urea easily enters through stomata and other openings and is assimilated by the plant cells. It is easily distributed through the phloem from source to sink inside the plant as per its need.

Application of nano urea on rice crop, resulted in unutilized nitrogen being stored in the plant vacuole and is slowly released for proper growth and development of the plant and also the experiment was reported that application of mineral fertilizers (NPK) at 100% RDF tends to increase the height, shoot and root length of rice plants. At the same time, the application of nano urea (spray) with fertilization (NPK) had significant impact on the growth parameters particularly at critical periods (Velmurugan *et al.*, 2021)

Increased concentration of nano spray (4%) had significant impact on the plant growth parameters due to increased availability of N within the plant system. Consequently nano spray helped the rice excess mineral N applied through chemical fertilizer as it is used in the plant system. This is mainly due to controlled release of nano nitrogen (Kashyap *et al.*, 2015). Application of nano urea (spray) with fertilization (NPK) had significant impact on the growth parameters particularly at critical periods. In brief nano spray contributed to the increased plant yield (15-21 %) than only NPK addition through chemical fertilizers.

The primary reason for better performance of rice receiving two nano sprays was due to nano pores and stomatal openings in plant leaves which facilitated nano material uptake and their penetration deep inside leaves leading to higher nutrient use efficiency (NUE). Precisely nano fertilizers have higher transport and delivery of nutrients through plamodesmata, which are nano sized (50-60 nm) channels between cells (Mahanta *et al.*, 2019).

NANO-FERTILIZER IN WHEAT

Higher biological yield and grain yield were recorded in wheat grown with spraying of Nano-fertilizers Super Micro Plus (NSMP). The highest grain yield was obtained in NSMP, followed by sole tri nano (N+P+K) treatment. (Hayyawi *et al.*, 2018)

Hayyawi *et al.,* (2018) reported that the wheat grain protein content (13.69 %) was high under the treatment of nano super micro plus application and which was on par with application of tri nano (N+P+K) fertilizer (13.33) when compared to other treatments. While the productivity of fertilizers achieved was significantly high when treated with NSMP and Nano (N+P+K) (1936.0, 1581.0 Kg Kg-1) respectively compare with all other treatments of foliar feeding including the traditional one.

Nano-fertilizer are easily absorbed by the epidermis of leaves, translocated to stems which facilitated the uptake of active molecules and enhanced growth and productivity of wheat (Abdel-Aziz et al., 2018)

Foliar application of super micro plus nano fertilizer at the rate of 1 kg ha^{-1} was optimum fertilizer treatment for growth, yield, nutrient uptake and fertilizer productivity, the results in this study showed that there was generally a positive effect of combined nano N+P+K, N+P, N+K, P+K and traditional NPK+TE nutrients supply on growth and yield parameters of wheat in Iraqi conditions compared with control. (Hayyawi *et al.,* 2018)

Wheat yield components: SNPs applied @ 25 ppm produced significantly greater number of grains $spike^{-1}$ (29.0) followed by 75 ppm (25.0). The lowest number of grains spike-1 (11.5) was recorded with 150 ppm of SNPs applied (Jyothi and Hebsur, 2017).

NANO-FERTILIZER IN MAIZE

Bada Maheswara reddy *et al.,* (2022) reported that the maize grain yields differed considerably when 50% N was provided by urea and 50% N was provided by Nano urea in combination with Nano Zn. Nano fertilizers in conjunction with traditional fertilizers improve nutrient absorption efficiency. It boosted photosynthesis and nutrient translocation, increasing productivity and grain output.

Amany *et al.,* (2019) stated that the maximum grain yield and biological yield were obtained by N: 80 P: 15 kg/fed applied. This application saved about 33.33% of mineral NP fertilizer which reduced environmental pollution and cost of fertilizer. Nano micronutrients fertilizer foliar application (@ 200 g/fed) stimulated maize grain yield.

The increase in grain yield due to foliar application of nano micronutrients at100 and 200g/fed were 10.45 and 14.40% compared to control. This indicated that applied nano micronutrients fertilizer clearly increased maize grain yield and its components (Amany *et al.,* 2019; Mosavifeyzabadi *et al.,* 2013; Farnia and Omidi, 2015; Babaeia *et al.,* 2017 and Tiwari, 2017).

Several investigators indicated that applied nano micronutrients fertilizer clearly improved growth traits of maize. Plant height and dry matter weight increased due to application of zinc oxide nanoparticle (Adhikari *et al.,* 2015).

Adhikari *et al.* (2016) noted that application of Cu nano-particles enhanced the growth (51%) of maize plant in comparison to control. Leaf area, stem diameter, relative water content, and chlorophyll content enhancement due to application of complete nano-micronutrients (Fe, Cu, Zn, B, Mn) over the control (Janmohammadi *et al.,* 2016 and Subbaiah et al., 2016)

NANO-FERTILIZER IN GROUNDNUT

The experiment was conducted in college farm, college of Agriculture, Rajendranagar, Hyderabad to explore the effect of Bio and Nano P fertilizer (soil application of bio and nano P @65 kg ha^{-1} and foliar application of bio Phosphorus @2 and 4ml l^{-1} and nano Phosphorus @1 and 2ml l^{-1} respectively) in terms of yield and yield attributes and quality of Groundnut (*Arachis hypogaea* L.) In all these characteristics, application of phosphorus at 40 kg ha^{-1} and application of bio and nano formulations increased the number of pods per plant, number of kernels per plant, hundred kernel weight by 8.4%, 16.3% and 19.4% over control, respectively. Similarly application of nanophos at 65 kg ha^{-1} resulted in increase in the number of pods per plant, number of kernels per plant, hundred kernel weights by 6.6%, 14.7% and 14.2%, respectively over control and this was followed by foliar application of biophos@4 ml l^{-1} and 2 ml l^{-1}. (Swetha Kumari *et al.,* 2017)

NANO-FERTILIZER IN SUGARCANE

According to Mahmoud Alimohammadi *et al.,* (2020) maximum cane (83.7 ton ha^{-1}) and maximum sugar production (8.04 ton ha^{-1}) were obtained with 161 kg N ha^{-1} supplied from Nano-Nitrogen Chelate Fertilizers (NNC) fertilizer. Also the lowest cane (59.3 ton ha^{-1}) and lowest sugar production (5.44 ton ha^{-1}) were obtained with 80 kg N ha^{-1} supplied from NNC and urea fertilizer, respectively. Different amounts of sugar production in treatments are due to differences in sucrose percentage and cane yield (fresh weight).

APPLICATION OF NANOFERTILIZER IN HORTICULTURAL CROPS

Vegetables: Productivity of **potato** cv. Arizona, fertilizer use efficiency and agronomic use efficiency could be increased by fertigation with nano NPK fertilizers (Hayyawi *et al.,* 2019). **Tomato** (*Lycopersicon esculentum*) yielded highest number of fruits per plant, fruit weight, fruit diameter by application of 300 kg/ha K nano-fertilizer, and the highest plant height and stem diameter was observed under application of 400 kg/ha K nanofertilizer (Ajirloo *et al.,* 2015). Application of Ferbanat nanotechnology liquid fertilizers @ 3 L/ha to **cucumber** crop gave highest fruit diameter (Melek *et al.,* 2014). Jackiene *et al.* (2015) applied bio organic nanofertilizers prepared from cattle manure at a dose of 0.5 or 1 litre/ha at beginning of intensive **sugar beet** development (BBCH 18 and BBCH 37-38) singly or doubly. It was observed that all treatments improved photosynthesis process and productivity of **sugarbeet**. Compared to control plants 1 L/ha dose increased leaves number by 19.6 %, leaf area by 13.4 %, diameter of root by 11.1 %, canopy dry mass by 29.1 %, root biomass by 42.6 %, net photosynthetic productivity by 15.8 %, root yield by 12.6 %, sucrose content by 1.03 % and white sugar yield increased by 19.2 %. Nor et al. (2017) studied the effect of nano-fertilizer NPK 20:20:20 at 4, 8, 12 kg/ha and commercial single fertilizer NPK 34:56:56 kg/ha as soil application on dwarfed **long bean**. All the treatments showed increase in chlorophyll content and number of leaves. Nano-fertilizers at 8 kg/ha showed best result. Nor *et al.* (2018) studied the impact of nano-fertilizer NPK 20:20:20 @4, 8 and12 kg/ha and single NPK 34:56:56 kg/ha on dwarfed long bean. It was observed that all the treatments showed significant increase in growth, height and stem diameter in the treated plants. **Drumstick** (*Moringa oleifera*) was treated with nano chelated iron at 0, 1, 2, 3 and 4 mg/L, GA3 at 0, 200 and 400 mg/L and organic fertilizer Acadian at 0 and 1 mg/L. Nanofertilizer and GA3 at lower concentration showed positive response on the production of α-tocopherols, stigmasterols and campesterol (Kadim, 2018). Iron 2 mg/L, nano iron 2, 4 and 6 mg/L and control treatments were given as foliar spray to Faba bean (Vicia faba L.) at three times interval i.e. vegetative stage, before flowering and at flowering stage. It was observed that protein percent, chlorophyll content and grain yield increased with increasing nano iron concentration. Nano iron with 6 mg/L spray gave highest grain yield (Nadi *et al.,* 2013). **Red bean** (Phaseolus vulgaris L.) treated with N bio fertilizers showed increase in yield and yield components. It was also observed that K- chelate nanofertilizers could replace chemical fertilizers (Farina and Ghorbani, 2014). Ladan Moghadam et al. (2012 investigated on the effect of nano iron chelate on growth and yield of 2 **Spinach** variety Varamin 88 and Viroflay. The research findings shows that iron chelate nanofertilizers improved wet weight by 58 and 47 % maximum leaf area index. It shows that nanofertilizer has a positive effect on all stages of plant growth and development. Cucurbita pepo L. cv. White Bush marrow when treated with nano SiO_2 had increased growth and germination of plant, enhanced photosynthetic activity, reduced degradation, improved water use efficiency thereby improved plant defence mechanism of plant and stress (Siddiqui, 2014). Wang *et al.* (2011) experimented on effects of nano-preparation on growth and nitrogen fertilizer use efficiency in cabbage.

Conclusion

The extensive use of agrochemicals to boost agricultural production has polluted not only the soil, groundwater and food. Increasing agricultural productivity is necessary to supply the demand of food grains, but keeping the in mind the damage to the ecosystem new approaches need to be considered. Nano nutrients are more efficient and economical than conventional ones. Application of different types of nano-fertilizers has a major impact on yield of crops, the protection of natural resources and the reduction of fertilizer cost for crop production. With the use of nano-fertilizers in agriculture fields, nutrient use quality will be increased. The nano-fertilizers promote good crop growth and yield by proper dosage and concentration. The future of nanofertilizers for sustainable crop production and time period needed for their general adaptation as a source of plant nutrients depend on varied factors such as effective legislation, production of novel nanofertilizers products as per requirement and associated risk management. There is a dire need for standardization of nanomaterials formulations and subsequently conducting rigorous field and greenhouse studies for performance evaluation. For sustainable crop production, smart nanofertilizers having the potential to release nutrients as per plants requirement in temporal and spatial dimensions must be formulated. However, research scholar and scientists need to shoulder the responsibility by providing further insights in order to take full advantage of the nanofertilizers for sustainable crop production under changing climate with the risk of causing environmental pollution.

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