Review Article

Efficient Use of Nano-Fertilizer for Increasing Productivity and Profitability along with Maintain Sustainability in Rice Crop: A Review

Abstract

The need for food and the expanding global population have put enormous pressure on agriculture to increase crop yield while preserving sustainability. Since rice is a staple diet for millions of people, novel methods are needed to increase yields without harming the environment. The possible advantages of using nano fertilizers in rice farming are examined in this abstract in order to raise yields, increase farmer profitability, and ensure long-term sustainability. Nano-sized carriers created for effective nutrient delivery to crops are called nano fertilizers, an innovative application of nanotechnology in agriculture. Their special qualities, such as their large surface area and regulated release mechanisms, allow for the targeted supply of nutrients to rice plants, improving nutrient uptake and utilization. Nano-fertilizers successfully optimize nutrient availability as a consequence, increasing crop output. According to studies, using nano fertilizers in rice farming increases grain yields because plants are better able to absorb and assimilate nutrients. The crop's resistance to environmental challenges and disease strains is strengthened as a result of this enhanced nutrient utilization, which also boosts yield and contributes to sustainable rice farming practices. Furthermore, nano fertilizers offer cost-effectiveness and increased profitability for farmers. Despite their initial higher cost, the efficient nutrient delivery of nano fertilizers reduces the overall application rate required compared to conventional fertilizers. This reduction in input costs translates to improved profitability for farmers, promoting economic sustainability in rice production.

Keywords: *Agriculture, environment, farmer, fertilizer, nano, nutrient, sustainability.*

1. INTRODUCTION

Rice (*Oryza sativa L*.) belong to family *Poaceae* and rice was believed to have originated from South-East Asia. In both regions of the temperate world and the tropics, it is one of the most significant cereal crops. A variety of agricultural ecologies, including irrigated uplands, rain-fed lowlands, and rice habitats that are vulnerable to flooding, are used to grow rice. A staple crop in agriculture, rice is crucial in providing food for billions of people throughout the world. Its cultivation has a long history and is intricately linked to the development of civilizations. Rice is a crop that may be grown in a variety of climates because of its Asian roots. Its value is in moulding cultural norms and traditions in addition to providing food. Rice production supports rural economies and provides livelihoods since it is the most important agricultural product. However, it has issues with climate change and sustainability. Understanding the role that rice plays in agriculture is essential for ensuring food security and meeting the changing requirements of a world population that is expanding. India comes second to China in terms of area and production among the world's major rice producing nations. Out of 782 million tonnes of global rice production from 167.1 million hectares, India produced 116.42 m t in 44.5 m ha (rainy season: 102.13 m t from 39.27 m ha) (FAO, 2020; GOI2020). Over 2 billion people in Asia alone rely on rice, which includes 80% carbs, 7-8% protein, 3% fat, and 3% fiber, to meet 80% of their energy needs. About 43% of India's total food grain output comes from rice, making it one of the leading food grain producers. Over 2 billion people in Asia alone rely on rice, which includes 80% carbs, 7-8% protein, 3% fat, and 3% fiber, to meet 80% of their energy needs. About 43% of India's total food grain output comes from rice, making it one of the leading food grain producers. (Upendra *et al.,* 2013).

Fertilisers are essential for increasing food output and quality, especially for cultivars that are high-yielding and receptive to fertilizer. To produce and yield more rice, a vast number of inorganic data sources are required. According to (Masum *et al.* 2013), the availability of nutrients including nitrogen, phosphorus, potassium, sulphur, and zinc as well as the state of the soil have an impact on rice productivity. Rice crops necessitate a lot of mineral and supplements as well as nitrogen for their growth and development and production of grain (Ma, 2004). By decreasing nutrient losses during fertilizer application, emerging technologies like nanotechnology and nanoparticles can be employed to boost rice output. Nano fertilisers may increase plant metabolism due to their special physicochemical characteristics (Giraldo *et al.* 2014). The nano-fertilizers or nano encapsulated nutrients might have the properties that are effective to crops, release the nutrients on demand, controlled release of chemical fertilizers that regulate the plant growth and enhanced target activity (DeRosa *et al*. 2010). Therefore, the aim of agricultural researchers is to produce sustainable agriculture with increased output while maintaining the welfare of society. As a result, the use of chemical fertilisers has long been criticized due to their negative effects on the environment and the quality of agricultural goods, and researchers are always searching for better alternatives. There have been studies done to increase rice output, but only two or three employing nanomaterial's can be found in the literature. The nutrients that are needed in considerably smaller amounts than vitamins and minerals are referred to as micronutrients. Vitamins like boron, copper, iron, manganese, molybdenum, zinc, and chloride are examples of micronutrients. Even though they are needed in minute amounts, micro nutrients are vital for healthy plant growth and productive crop production (Juthery 2021).

The advantages of dynamics in form, size, surface area, and bio assimilation are used in these nano scale items. The research organizations assessed nano fertilizers through 11,000 on-farm trials on progressive farmers' fields across the nation in 2019–20, encompassing 94 crops and multiple locations and crop types. The benefits of nano-fertilizers (Nano N, Nano Zn and Nano Cu towards increasing nutrient use efficiency and crop productivity and produce quality in general and of IFFCOs Nano-Urea , Nano-Zn and Nano Cu in particular (Kumar 2021). Nano-fertilizers and slowly released fertilizers are appropriate alternatives to conventional fertilizers for gradual and controlled supply of nutrients in the soil

(Rathnayaka 2018). Given that soil and plant-water connections, as well as fertilizer management, have a significant impact on agricultural production systems, nutrient efficiency is one of the most pertinent criteria for evaluating these systems. Research on increasing nutrient usage efficiency is now highly important and difficult. To achieve optimum production and promote the health of the crop and soil, nutrients are given to crops and cropping systems. Transport of the Nano formulated nutrients to various plant regions. Due to their high surface area to volume ratio, nano-fertilizers outperform regular fertilisers very well. At the same time, encapsulation of nutrients to vegetable crop increases the supply of nutrients to the plants (Mahanta 2019). When ZnO nanoparticles were seed primed at 75 and 100 mg/l in wheat, the concentrations of zinc in the shoots and roots rose by 12% and 24%, respectively, over the control (Rizwan *et al*., 2019). The effectiveness of nano fertilizers in agricultural areas will be evaluated in this study.

2.1 NANO- FERTILIZERS

Nano materials are single units ranging in size from 1 to 100 nm in at least one dimension (Liu and Lal 2015). The next stage in applying nanotechnology to more sustainably farm is nano fertilisers. The term "nano fertilisers" describes a novel class of plant nutrients that have been developed at the nanoscale. These nanoscale fertilisers help to increase the effectiveness of nutrient utilization and environmental quality by reducing nutrient losses from leaching and avoiding chemical changes (Saharan *et. al.,* 2016 and Raliya *et. al.,* 2017). Enhanced fertilizer delivery and improved plant nutrient absorption efficiency are provided by these tiny particles. Their nano size enables more effective nutrient absorption and tailored nutrient delivery to plant cells, increasing crop yields and minimizing environmental impact. The nanoscale particles are smaller in size and may be absorbed with different dynamics from those in bulk particles or ionic salts, which has significant benefits (Chugh *et. al.,* 2021). The usage of nano-enabled fertilizers may improve nutrient delivery efficiency in plants (Chhipa 2017) as nano fertilizers have demonstrated a boost in productivity by ensuring targeted delivery/gradual release of nutrients and reducing fertilizer application with an increase in NUE (kah *et. al.,* 2019). By enhancing food output, maximizing nutrient use, and promoting sustainable farming methods, nano fertilisers have the potential to revolutionize agriculture. Further investigation and analysis are necessary, nevertheless, to determine their long-term impacts on ecosystems and human health.

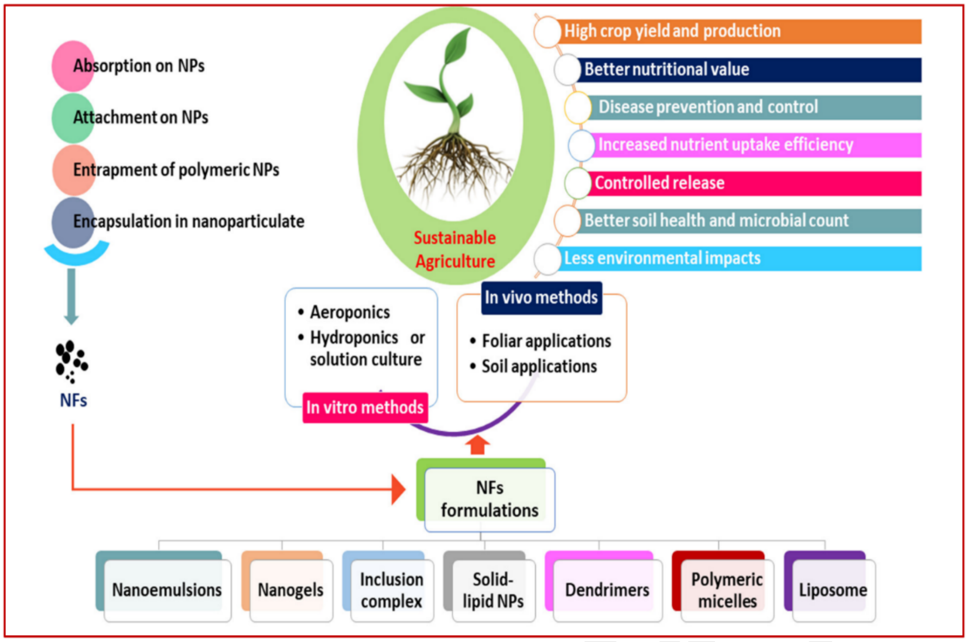

Figure 1: An overview of Nano fertilizer application in agriculture.

2.2 ROLE OF NANOFERTILIZERS

In order to enhance food production in the twenty-first century, agriculture must handle a number of issues, including the world's population growth that is happening at an accelerated rate, the unpredictable nature of climate change, the productivity of agriculture, the elasticity of the labour force, and the expanding urbanization. According to reports, between 40–70% of the nitrogen, 80–90% of the phosphorus, and 50–90% of the potassium in applied fertilisers 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 dwindling resources and an ever-increasing global population, agriculture has always been crucial as a source of food, feed, and fiber. (Brennan 2012). Nanotechnology is a potentially useful instrument that might usher in a new era of precision farming methods, making it a viable answer to these issues. Even in difficult circumstances, nanotechnology may boost agricultural potential to provide larger yields in an environmentally sustainable manner (Sugunan and Dutta 2008). Nano fertilizer may regulate the release of nutrients and deliver the correct quantity of nutrients required by the crops in suitable proportion and promote productivity while ensuring environmental safety (De Rosa *et al.* 2010). During the past few years, there has been extensive interest in applying NPs to plants for agricultural management (Nanotechnology in Agriculture and Food 2006; Torney *et al.* 2007; Khodakovskaya *et al.* 2009, 2012; Husen and Siddiqi 2014; Razzaq *et al.* 2016). We are aware that under nutritional limitation, plants release carbonaceous chemicals into the rhizosphere, which can serve as environmental cues for the development of innovative Nano fertilizers (Sultan *et al.* 2009). Novel nano fertilizer application has an edge over traditional methods of fertilizer application by releasing nutrients in a controlled manner, preventing eutrophication and pollution of water resources (Sekhon 2014; Naderi and Abedi 2012). The usage of nano fertilizer increases the elements' use efficiency while also decreasing the toxicity produced by fertilizer over application in the soil and fertilizer split application (Naderi and Danesh-Shahraki 2013).

2.2.1 Higher nutrient use efficiency-

Nano fertilizers have high surface areas, and this can provide a maximum reactivity and increase both the availability of nutrients and plant NUE (Liscano *et. al.,* 2000 & Siddiqi husen 2017). Furthermore, nano fertilisers have a high water solubility due to their small particle size and strong adsorption and fixation to soil particles, whereas synthetic fertilisers have a poor water solubility due to their big particle size. In order to maximize the absorption and availability of fertilisers by plants and to reduce their bulk needs, fertilisers are encapsulated in nanoparticles (Chhipa 2017). Utilizing zeolite-based nano fertilizers, for instance, makes it feasible for plants to have high nutrient availability during the whole development phase. Furthermore, the slow and targeted nutrient release (Singh *et. al.,* 2017) of nano fertilizers minimizes their toxicity to plants (Sohair *et. al.,* 2018) and decreases N losses via volatilization, leaching, fixation, and denitrification, as well as salt accumulation in soil.

2.2.2 Abiotic Stresses are mitigated by Nano-Fertilizers-

The large surface area and nanoscale size of nano materials, which assist plant growth and development under biotic and abiotic challenges, have significantly increased the functioning of biological systems (Rajput *et. al.,* 2021), *viz.,* drought, salinity, alkalinity, temperature, minerals and metal toxicity (Sharifi *et. al.,* 2020). Due to the fact that photosystem II, rubisco, and ATP synthase become the main targets of stress, photosynthesis, a crucial metabolic activity in plants, is discovered to be the most sensitive to it (Adisa *et. al.,* 2019). Plant defense responses to abiotic stress have been established with SiO2 NPs to improve transpiration/ water-use efficiency, photosynthetic pigments, and carbonic anhydrase activities in pumpkin plants (Siddiqui *et. al.,* 2014). The main sign of abiotic stress is the production of reactive oxygen species by cell organelles in stressful circumstances. In order to combat the oxidative stress that their environment causes, plants have the enzyme machinery necessary.

2.3 THE KEY TO SUSTAINABILITY IS INNOVATIVE NANO FERTILISERS

A benefit of new and creative fertilisers, in addition to improved nutrient absorption effectiveness, is that they have a smaller environmental imprint. A sustainable way to increase agricultural production with little environmental effect is provided by cutting-edge nano-fertilizers. Their delivery of nutrients at the nanoscale increases plant absorption, lowers waste, and encourages effective resource use, encouraging long-term ecological balance for a more sustainable and secure supply of food in the future. A new, high-tech fertilizer that is also financially accessible might be a true solution for the heavily subsidized Indian fertilizer sector. Nanotechnology can be leveraged to develop agricultural intensification solutions, which can increase food production per unit of inputs and resources (Kumar *et. al.,* 2021). Due to their small advantage and regulated production process using chemical, physical, and biological techniques, nano fertilizers based on nanotechnology have emerged as a potential solution to fill this gap in the traditional and novel fertilizer markets.

2.4 MECHANISMS OF NANO-FERTILISERS' UPTAKING AND ACCUMULATION FROM SOIL TO PLANT

The physicochemical characteristics of the soil, such as its texture, structure, clay minerals, pH, cation exchange capacity, soil organic matter, and microbial population, have an impact on the dispersion, aggregation, stability, immobilization, bioavailability, and transit of nano particles (Khalkhal *et. al.,* 2020). Due to the surface charge effect, dissolved organic matter impacts the aggregation, mobility and binding nature of NPs (Li *et. al.,* 2017). Nano-fertilizers can be sprayed directly onto the ground or plant life. The root entry follows the foliar entry in order of appearance. While root treatment gains access through root tips, lateral roots, root hairs, and rhizodermis, foliar application—provided by spraying the green canopies/leaves—obtains access primarily through the cuticle, stomata, and hydathodes. Nano fertilizers foliar application is preferred during poor soil and weather conditions (Mittal *et. al.,* 2020). The flow of water and solutes through the soil is described by the Richards equation, and the convection–dispersion equation with different empirical models using the Michaelis–Menten equation (Barber 1995 and Claassen *et. al.,* 1986). As the concentration of nutrients grows, absorption increases in a nonlinear manner until it reaches the maximum uptake. The Michaelis-Menten equation's kinetic parameters are affected by the kind of plant, how long it grows, how hot the soil is, and other variables. The steady-state source-sink model with flow driven by an osmotically produced pressure gradient was the first nutrient transport model for plant tissues (Thornley and Johneson 1990 & Minchin et. al., 1993) influenced by diffusive transport factors (Payvandi *et. al.,* 2014); still, efforts are needed to acquire a perfect uptake model/mechanism for nano particles in plants.

2.5 NANO-TECHNOLOGY FOR NUTRIENT MANAGEMENT IN RICE

The goal of using nanotechnology in agriculture is to reduce the use of hazardous pesticides, reduce nutrient losses during fertilization, and boost output through better nutrient management (Prasad *et. al.,* 2017). A key concern is the pitiable utilization effectiveness of current fertilisers. China is the greatest consumer of nitrogen fertilizer in the world, and up to 50% of it can be lost through volatilization and another 5–10% through leaching (Kah *et. al.,* 2018). Fertilizers loss can cause serious environmental issues, i.e., eutrophication (Tilman *et. al.,* 2018). By increasing the bioavailable portion of nutrients (such as phosphorus and zinc) or by limiting the loss of mobile nutrients to the environment, such as nitrate, nanotechnology is intended to improve the efficiency of fertilizer usage in the field of plant nutrition (Liu and Lal 2015). The use of excessive amounts of fertilisers, such as nitrate or phosphate compounds, ammonium salts, and urea, has significantly enhanced food production, but these fertilisers also have a negative impact on the healthy soil micro biota. Innovative approaches for managing nutrients in rice farming are provided by nanotechnology. Nanoparticles, like nano urea, improve nutrient uptake efficiency, controlled nutrient release, and stress tolerance in rice plants, leading to enhanced growth and yield (Kumar *et. al.,* 2021). In contrast to other particles with conventional surfaces, nano-coated particles have considerable surface tension, which contributes significantly to the sluggish release of fertilizer. Additionally, nano-coatings are used to surface protect bigger particles. (Duhan *et. al.,* 2017). Due to the nano-coating's durability, fertilisers may release more gradually into the soil, where they can be more effectively absorbed by plants. Slow release fertilizers usage has become an advanced approach to overcome the gigantic problems of environmental pollution and excessive fertilizer consumption (Wu and Liu 2008). Numerous polymers have been employed to release fertilisers gradually and sustainably in order to fulfil crop needs.

2.6 IMPACT OF NANO NITROGEN IN RICE

Nano-based slow-release or controlled-release fertilisers offer enormous potential to increase the efficiency of nutrient utilization. Nanofertilizers may control the release of nutrients, give the right amount of nutrients to crops in the right proportions, and increase yield while protecting the environment (De Rosa *et al.* 2010). Rahale (2010) found that compared to control, nanofertilizer enhanced NUE by up to 45%. She also stated that even 1176 hours later, nanozeolite was still releasing nitrate, with quantities ranging from 110 to 114 mmol L-1. The findings clearly showed that while traditional fertilizer only releases nitrogen from nanozeolite for 8 days, it does so for more than 45 days. Nano urea enhances rice growth and yield through improved nutrient uptake efficiency and controlled nitrogen release, leading to increased biomass and higher grain production (Kumar et. al., 2021). Application of 100% recommended NPKZn +2 foliar sprays of nano urea each @ 2ml/liter of water recorded significantly higher effective tillers m number of grains panicle , 1000-grain weight, grain yield and straw yield of rice (Attri et. al., 2022). The maximum highest plant height (104.7 cm), number of tillers (348) and grain yield (7056 kg ha-1), straw yield (8342 kg ha-1) found in the treatment 50% RDN + 50% Nano N (Midde *et. al.,* 2021). In contrast to conventional fertilisers, nano nitrogen reduces the environmental concerns while improving rice growth, yield, and nutrient uptake efficiency. Nitrogen losses and pollution are decreased by its controlled release technique. Studies point to better plant health and insect resistance. However, for sustainability to last over time, rigorous investigation and appropriate usage are crucial (Kottegoda *et. al.,* 2021).

2.7 IMPACT OF NANO PHOSPHORUS IN RICE

Due to its essential function in the energy transfer molecules ATP, ADP, phospholipids, and sugar phosphate, as well as its participation in activities like photosynthesis, respiration, and the manufacture of DNA, phosphorus is regarded as the second most important nutrient for maximum plant development (Soliman *et. al.,* 2016). Different parameters of plant productivity such as root and shoot length, plant vigor, resistance to diseases, number of reproductive buds, yield, and quality of rice are strongly influenced by the availability of P (Preeth and Balakrishnan 2017). P in synthetic fertilisers, however, has a limited availability due to its prolonged release period and strong soil fixation. Rice growth characteristics have been positively impacted by nano-phosphorus, including improved nutrient absorption, improved root and shoot development, and higher chlorophyll content (Gong *et. al.,* 2019). Nano-sized phosphorus particles have shown significant positive impacts on rice yield. They enhance nutrient absorption, promote root growth, and improve overall plant health. This leads to increased grain production and higher crop yield (Khan *et. al.,* 2018). The growth and production of rice crops have been discovered to be greatly improved by nanophosphorus. Increased grain production results from its application, which encourages root growth, nutrient absorption, and photosynthetic effectiveness (Sadati, *et. al.,* 2021). Application of phosphorus as superphosphate or nano-phosphorus enhanced grain quality characteristics as well as nitrogen and phosphorus content in milled grains (Sorour *et. al.,* 2020).

2.8 IMPACT OF NANO ZINC IN RICE

Zn nutrition is crucial for plant growth since it is a structural co-factor for many proteins and enzymes. Additionally, zinc is necessary for the control of auxins, protein metabolism, glucose biosynthesis, and a plant's defense against infections and environmental challenges (Broadley *et. al.,* 2007). Modern agriculture regularly uses zinc nano fertilizers in the form of ZnO because they are more effective and economical than synthetic Zn fertilisers and may be used for soil mixing, seed priming, and foliar spraying. However, trace elements such as Zn can negatively affect plant growth via producing some metabolic alterations in plants if they applied in high doses (Ali *et. al.,* 2020). Studies have revealed that the application of Zn NFs can increase the germination, seedling growth, yield, and quality of crops (Seleiman *et. al.,* 2020). Nano zinc has shown promising results in improving growth and yield in rice. Its enhanced bioavailability facilitates better nutrient uptake, leading to increased plant vigor and higher grain production (Nile *et. al.,* 2022). Nano zinc application in rice has shown significant positive effects on yield. It enhances nutrient uptake, increases photosynthetic efficiency, and improves overall plant health, leading to higher grain production (Sharma and Sohu 2021).

2.9 IMPACT OF NANO COPPER IN RICE

Rice with nano copper has the potential to significantly alter farming methods. Its improved nutrient uptake, boosted plant development, and increased crop output can all be attributed to its improved dispersion and absorption in plants. It could also lessen the demand for traditional insecticides with copper bases, reducing environmental pollution. However, it is crucial to carefully monitor its possible toxicity and long-term consequences on the health of the soil. By promoting root development, nutrient absorption, and disease resistance, nano copper has demonstrated encouraging impacts on rice growth. The small size and increased surface area of nano copper particles allow for better absorption and utilization by rice plants (Yang *et. al.,* 2020). The effects of nano copper on rice yield and growth have been encouraging. Utilising nano copper-based formulations has been shown to boost plant growth, chlorophyll content, and nutrient absorption. Rice production rises as a result of the special features of the nanoparticles, which improve vital element absorption and translocation. However, it is essential to consider potential environmental implications and safety concerns related to nanoparticle use in agriculture. (Luksiene 2017). The effects of nano copper on rice yield characteristics have been encouraging. According to studies, using nano copper greatly improves key rice growth indicators including plant height, tiller count, panicle length, and grain weight. The higher nutrient intake and physiological processes made possible by nano copper are responsible for the better yield characteristics (Kothari *et. al.,* 2023).

2.10 ADVANTAGE OF NANO FERTILIZERS IN RICE

Rice farming can benefit greatly from nano fertilisers. These fertilizers' nanoscale size allows them to effectively transfer vital nutrients right to the plant cells, improving nutrient absorption and utilization. The structure of nano fertilizer contains no ethylene components. This focused strategy reduces nutrient loss due to leaching and volatilization, increasing the efficiency of nutrient usage. Additionally, nano fertilizers can enhance soil water retention and structure, fostering better root development and greater plant health. The variety, stability, and size of nanoparticles produced using biological or green technology are excellent. Synthesis of nanoparticles can be done by chemical, physical and biological techniques (Mohanty *et. al.,* 2005). Higher yields and improved crop quality are produced as a result of their regulated release mechanisms, which provide a consistent nutrient delivery throughout the lifespan of the crop. Additionally, nano fertilizers are safe for the environment and less likely to contaminate soil and water, making them a viable option for ecologically friendly rice farming. Microorganisms are cultivated over specific nutrients under the right circumstances in order to synthesize nanonutrients. After desire growth, the biomass was detached, and the filtrate was used for isolation of extracellular specific proteins, and these were used for nanoparticle synthesis (El-Ramady *et. al.,* 2018). In the growth of rice, nano fertilizers have various benefits. They promote soil health, boost agricultural output, improve nutrient absorption, and lessen environmental pollution. Additionally, regulated and targeted nutrient delivery is made possible by nanotechnology, which results in effective resource use.

3. CONCLUSION AND FUTURE PROSPECTS

Nano-fertilizers in rice have shown promising results in enhancing crop yield and nutrient uptake while reducing environmental impacts. Studies highlight their potential to improve soil health and increase rice resistance to abiotic and biotic stresses. Despite these positive outcomes, more research is needed to assess long-term effects on ecosystems and human health. Future prospects lie in optimizing formulations, understanding nanotoxicity, and integrating nanotechnology into sustainable agricultural practices. Striking the right balance between innovation and environmental safety will be crucial in realizing the full potential of nano-fertilizers for rice cultivation.

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