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Review on nitrogen use efficiency in wheat crop using Nano urea and conventional urea fertilizer

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Abstract

Conventional chemical fertilizers, notably urea, have long been employed globally to meet the increasing demands for food production. However, the use of conventional urea has raised environmental concerns, including nitrate leaching, global warming, ozone layer depletion, and groundwater pollution. As the global population grows and arable land diminishes, the demand for chemical fertilizers, particularly nitrogen intensifies. Nano-fertilizers, characterized by nano-dimensions and slow-release properties, offer a potential solution. They serve as efficient nutrient carriers, minimizing losses through leaching and emissions. Nano-urea, developed by IFFCO, stands out with nanometer-sized particles, prolonged shelf-life, andreduced environmental impact. Its adoption holds promise for sustainable agriculture, reducing agro-chemical use and enhancing soil health. Comparing nano-urea to conventional urea reveals higher efficiency, reduced environmental impact, controlled nutrient supply, and economic benefits. The Indian Agricultural Research Institute's experiment revealed that basal nitrogen application at 75% with prilled urea, full phosphorus and potassium, and nano-urea + nano-Zn sprays achieved yields comparable to 100% N + full P and K doses. Embracing energy-efficient novel fertilizers, such as nano-fertilizers, is crucial for achieving sustainable agriculture and meeting global food demands while mitigating environmental impacts.

Keywords: Nano-urea, urea, wheat, nitrogen, fertilizer

Introduction

Conventional chemical fertilizers are globally employed to enhance agricultural yields in response to rising food demands from the growing population. However, the post-green revolution era saw rampant and excessive use, causing environmental concerns [1]. As the global population increases and arable land diminishes, the demand for chemical fertilizers, particularly nitrogen, intensifies [2]. In 2019-20, the worldwide nitrogen fertilizer demand was 107.4 million tons, with 76.5% met by urea [3]. Despite its widespread use, urea production contributes to environmental problems like greenhouse gas emissions, water and electricity consumption, and potential pollution [4]. Addressing these issues, researchers propose reducing urea demand through energy-efficient fertilizers [5]. Conventional fertilizers, including urea, exhibit low efficiency (barely exceeding 30- 35%), leading to environmental consequences from excessive application to meet crop nutrient needs [6, 7]. Nutrient losses, through leaching (NO3-) or gaseous emissions (NH3 and N2O), contribute to environmental pollution [8]. In response, stakeholders seek alternative nutrient sources, with nano-fertilizers emerging as potential game-changers in agriculture [9, 10, 11, 12]. However, comprehensive research on their benefits compared to conventional fertilizers remains limited [13]. Nano-fertilizers, characterized by their nano-dimensions and slow-release properties, serve as efficient nutrient carriers with a higher surface area to volume ratio, minimizing nutrient losses through leaching and emissions (Babu *et al.* 2022), [10, 12]. Formulations based on nanoclays enable extended nutrient release, while coating fertilizer molecules with nano-membranes allows for the development of controlled-release fertilizers [14]. A notable example is nano-urea, developed and patented by the Indian Farmers Fertiliser Cooperative (IFFCO). This nano-urea, featuring particle sizes in the nanometer range, exhibits prolonged shelf-life, with at least 50% of particles measuring one nanometer.

With a physical particle size ranging from 20 to 50 nm and a hydrodynamic size from 20 to 80 nm, nano-urea contains 4% nitrogen (N) and a zeta potential greater than 30 [15]. The functional nutrients primarily originate from urea, treated with nonionic surfactants and stabilized in polymer matrices, forming nanoclusters below 100 nm. The adoption of nano-urea holds promise for sustainable agriculture practices, reducing agrochemical use, minimizing environmental pollution, and enhancing soil health [9, 10]. This, in turn, can lead to increased profitability and improved income for farmers, showcasing the potential of nano-fertilizers in transforming agricultural systems. To achieve sustainable agriculture and mitigate environmental impacts, embracing energy-efficient novel fertilizers, such as nano-fertilizers, is crucial. These innovations offer promise in reducing the environmental footprint and meeting global food demands.

Nano Urea

Nano urea, an innovative agricultural input based on nanotechnology, offers a particle size of 20 to 50 nm, providing a significantly larger surface area compared to conventional urea prills [9, 10]. The Indian Farmers Fertiliser Cooperative (IFFCO) nano urea (liquid) is officially recognized by the Government of India under the Fertiliser (Inorganic, Organic or Mixed) (Control) Order 1985. With a particle size of less than 100 nm, it contains 4% nitrogen (N) and has a shelf-life of approximately 2 years [16]. The liquid nano urea, with a zeta potential greater than 30 for stability, is applied by spraying at a rate of 2-4 mL per liter of water, depending on crop nitrogen requirements, canopy development, and water needs [17]. Application is timed during critical growth stages when the crop canopy is well-developed, ensuring effective foliar nutrient uptake. The first spray typically occurs 30-35 days after germination or 20-25 days after transplanting, with the second spray a week before flowering [17]. The number of sprays and concentration are synchronized based on specific crop nitrogen requirements.

Conventional Urea

Urea, the most widely used solid nitrogen fertilizer globally, plays a crucial role in providing essential nitrogen nutrition for plant growth. Produced through controlled reactions of ammonia gas and carbon dioxide at elevated temperature and pressure, urea is formed as molten urea and shaped into spheres or solidified into prills [18]. Its nitrogen content of 46%, cost effectiveness, and rapid conversion to plantavailable nitrogen contribute to its efficiency for transport and application. Urea offers versatility in applications, serving as a starter, broadcast, top-dress, or part of fertilizer mixes, both dry and liquid. In India, conventional granular urea accounts for over 82% of nitrogenous fertilizers,and the government addresses subsidy concerns to ensure affordability for farmers, as reflected in the substantial budget allocation of Rs. 67,187 lakh crore in the Union Budget 2022-23 [17].

Properties: Urea, with 46% nitrogen, is a versatile fertilizer available in granules or prills. It dissolves easily in water for irrigation or foliar application. Prone to moisture absorption, proper storage is essential volatilization (Tisdale *et al.*, 1985). Rapid conversion in soil ensures efficient nitrogen availability to plants, its also lead to losses of N through leaching, denitrification and volatilization (Tisdale *et al.*, 1985). Urea's versatility suits various crops and soil types for applications like starter fertilizer or topdressing.

Comparison with Conventional Urea

Comparing nano-urea to conventional urea is crucial for evaluating its potential as a fertilizer. Understanding the properties and performance differences is essential, given the widespread use of conventional urea in agriculture. There are some comparisons given below

Higher efficiency

Liquid nano urea boasts an impressive efficiency of up to 85%, a significant advancement over its conventional counterpart operating at only 25-30% efficiency [6]. This remarkable performance is attributed to nanotechnology, allowing the creation of extremely small particles with enhanced surfaceto-mass ratios. This enables precise and controlled nutrient delivery to crops, a stark contrast to conventional urea, where nitrogen is often administered inaccurately, leading to losses through evaporation or gas emissions [9, 11]. The regulated delivery of nano urea ensures it achieves the desired impact on crops. Moreover, nano nitrogen fertilizers substantially reduces nitrogen loss during irrigation, enhancing overall nutrient utilization efficiency [19]. This highlights the transformative potential of nanotechnology in optimizing fertilizer performance and mitigating environmental concerns associated with conventional urea application.

Less environmental effect: Liquid nano urea not only proves cost-effective but also presents an environmentally friendly crop nutrition solution [11]. Its reduced application requirement compared to conventional urea enhances crop nutrient efficiency, minimizing soil, water, and air pollution. The apparent nutrient recovery of conventional urea is generally in the range of 30-50% [20, 7], with the remaining amount lost through runoff, leaching, and volatilization, causing environmental issues. In contrast, nano urea liquid addresses these concerns by decreasing nitrogen losses and improving nutrient utilization,offering a more sustainable and eco-friendly approach to crop nutrition with potential positive implications for environmental conservation [9, 11].

Controlled and targeted supply of nutrient

Nano-structured fertilizers, characterized by their 1-100 nm size, exhibit heightened reactivity and water solubility due to a larger surface area. This enhances fertilizer response, crop yield, and quality while improving nutrient use efficiency. By reducing the risk of overdosing, these fertilizers contribute to agricultural sustainability, minimizing application frequency and production costs [21]. Liquid nano urea, when directly sprayed onto leaves, enables absorption through stomata, providing crops with a targeted nutrient supply. These nanoparticles enter plants and release nutrients in a controlled manner, targeting specific plant parts, reducing wastage, and minimizing environmental impact for a more efficient and sustainable crop nutrition approach [9, 11].

Economical

A 500 ml bottle of Nano-urea, costing ₹225 and 10% less than conventional urea, is equivalent to a 45 kg bag of urea. The subsidy-free liquid nano urea offers cost savings for farmers compared to the subsidized ₹242 bag of urea. Extensive trials by IFFCO reveal that Nano-urea can replace 50% of urea granules, potentially reducing urea fertilizer imports. This not only lessens the government's subsidy burden but also minimizes costs associated with transportation, storage, and nitrogen fertilizer usage.

Potential Benefits of Nano-Urea

Nano Urea is an innovative product that utilizes nanotechnology to fulfill the nitrogen requirements of plants. The benefits of Nano Urea are illustrated in (Fig. 2) and summarized as follows:

Enhanced nitrogen supply and improved nutrient utilization: Nano Urea, utilizing nanotechnology, ensures an efficient and targeted nitrogen supply to plants, enhancing nutrient uptake and utilization. This formulation is adept at being translocated and metabolically assimilated by plants, converting into essential proteins and amino acids [11]. The controlled release of nutrients during the crop's growth phase minimizes wastage through leaching, allowing plants to absorb the maximum amount [22]. Its application significantly reduces the demand for traditional urea by at least 50%. Additionally, Nano Urea enables higher productivity with fewer resources, as a 500 ml bottle is equivalent in efficacy to a conventional urea bag, exemplifying its potential for sustainable and resource-efficient agriculture [11].

Reduced environmental impact: Nano-urea promotes agricultural sustainability and environmental safety through energy-efficient and resource-friendly production. Its use reduces excess application, minimizing nitrogen wastage, pollution, and environmental footprint [9, 11].

Cost-effective and improves farmer's income: It offers cost savings as it is more affordable compared to conventional urea fertilizers. Because it optimizes the use of bulk nitrogenous fertilizers such as Urea. Applying nano-urea through foliar application during critical crop growth stages effectively fulfills the nitrogen requirement. The increased use efficiency of one bottle (500 ml) of nano-urea has the potential to replace at least one bag of conventional urea. Nano Urea results in higher income for farmers due to reduced input costs. Farmer field trials have shown an average increase of Rs 2000 per acre in income [23]. The nanotechnology facilitates metabolic assimilation of nutrients, resulting in produce with increased protein and nutrient content. Nano Urea adoption promotes sustainable agriculture, ensuring optimal crop yield and soil health, reinforcing its positive impact on both food safety and nutritional value.

Easy to store and transport: Nano Urea is needed in smaller quantities compared to bulky nitrogenous fertilizers like urea. This has a notable effect on logistics and warehousing costs. Farmers can conveniently carry bottles of Nano Urea instead of heavy bags of conventional urea. Despite the potential benefits, there may be limited long term research on the effects of nano urea on crop yields, soil health, and overall agricultural sustainability. More extensive research is needed to fully understand its implications.

Limitations in use of nano urea

The nanomaterials are very reactive because of their minute size with enhanced surface area [24]. Reactivity and variability of these materials are also a concern. This raises safety concerns for farm workers who may become exposed to xenobiotics during their application [25], impact of this in nano urea need to be studied. Precision in application is crucial, and incorrect use may lead to unintended consequences. Proper guidelines and education are essential for farmers to maximize benefits and minimize risks. There is a lack of standardized regulations for nano fertilizers, leading to uncertainty about their safety and environmental impact. The potential for nanomaterials to enter the food chain raises concerns about human health, and there's a need for comprehensive safety assessments. The environmental fate of nanomaterials in soil and water is not fully understood. There are concerns about the potential accumulation of nanoparticles in the environment, which could have long-term ecological consequences.

The Outcomes of field trials

Field demonstrations conducted in different places have demonstrated the effectiveness of liquid Nano urea in reducing the quantity of conventional urea required for meeting the recommended nitrogen dose by half (Table 3).The yields of wheat, maize, chickpea, and mustard increased by 5.77%, 7.29%, 8.36%, and 3.77%, respectively, in farmer's field trials using 50% less nitrogen compared to the N applied under farmer's fertilizer practice (FFP) and with two sprays of Nano nitrogen in standing crops [17]. Similar results were observed in field trials conducted by IFFCO on the use of liquid Nano urea in various crops, including rice, wheat, maize, tomato, cucumber, and capsicum, where two foliar applications at critical growth stages led to a 50% reduction in the application rate of conventional urea fertilizer and significant increases in crop yields ranging from 3% to 23% in wheat, 5% to 11% in tomato, 3% to 24% in paddy, 2% to 15% in maize, 5% in cucumber, and 18% in capsicum [11]. The experiment conducted at the Indian Agricultural Research Institute, New Delhi showed that the basal nitrogen application at 75% of the recommended rate through prilled urea, along with a full dose of phosphorus and potassium, along with nanourea (2,500 mL/ha/spray)+ nano-Zn (1,250 mL/ha) sprays, resulted in comparable grain yields (wheat, mustard, maize, and pearl millet) to 100% N + full P and K doses [26, 27]. For wheat, the application of the standard 100% recommended N dose (120 kg/ha) proved more productive than nano-urea-based treatments, including 50% recommended N dose+ 2 nanourea sprays and 75% recommended N dose + 1 nano-urea spray [28-30].

Conclusion

Nano-urea is an indigenous fertilizer manufactured by IFFCO, and its promotion can help reduce the financial burden associated with conventional urea imports. Research has demonstrated that utilizing 75% nitrogen with conventional urea, in combination with either one or two sprays of nano-urea, yields results on par with those achieved through the application of 100% nitrogen supplied via conventional urea. This suggests the potential of nano-urea in optimizing agricultural productivity while minimizing reliance on imported conventional urea. Its application significantly increases nitrogen availability to crops by more than 80%, leading to higher nutrient use efficiency. Additionally, nano urea helps in reducing the environmental footprint by minimizing nutrient loss through leaching and gaseous emissions, which were causing environmental pollution and climate change. This new form of urea would be advantageous for the agriculture sector, as it enables farmers to achieve comparable yields at a reduced cost of fertilizers. Nano urea is an environmentally sustainable option for farmers, promoting smart agriculture and contributing to climate change mitigation.

Recommendation for future research

Nano-urea is in its early implementation stages, providing an opportunity for strategic promotion. Testing various application approaches, such as 75% nitrogen as a basal through conventional urea with one spray at the active growth stage or 50% application through conventional urea with 1 to 3 additional sprays, is recommended. While current trials suggest the potential of Liquid Nano-Urea to enhance crop yields and minimize environmental impact, comprehensive field and laboratory testing is essential to ensure efficacy, biosafety, and bio-toxicity. Validation through multi-season field trials at research stations is crucial for reliable results. Additional studies are required to determine whether Liquid Nano-Urea can effectively substitute or supplement conventional urea, aiming to improve nitrogen use efficiency and crop yields without compromising food security and causing degradation of natural resources.

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