Recommendation- Follow the correction and improve it.

Add the proper references according to journal guidelines.

<u>Review Article</u>

A Comparative Study of Nano-urea and Conventional Urea: A comprehensive review

ABSTARCT

Conventional chemical fertilizers, notably urea, have long been employed globally to meet the increasing demands for food production. However, their excessive use post the green revolution has raised environmental concerns. As the global population grows and arable land diminishes, the demand for chemical fertilizers, particularly nitrogen, intensifies. Urea production, responsible for a significant portion of the global nitrogen fertilizer demand, contributes to environmental problems such as greenhouse gas emissions and pollution. Researchers advocate for reducing urea demand through energy-efficient fertilizers to address these issues. 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 the Indian Farmers Fertiliser Cooperative (IFFCO), stands out with nanometer-sized particles, prolonged shelf-life, and reduced 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. Nano-urea's nanotechnology-based innovations offer a transformative approach to crop nutrition, promoting sustainability, environmental conservation, and increased profitability for farmers. The Indian Agricultural Research Institute's experiment revealed that basal nitrogen application at 75% with prilled urea, full phosphorus and potassium, and

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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, Nitrogen, Nitrogen use efficiency, Leaching, Pollution

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 (Abebe *et al.*, 2022). As the global population increases and arable land diminishes, the demand for chemical fertilizers, particularly nitrogen, intensifies (Wen *et al.*, 2017). In 2019–20, the worldwide nitrogen fertilizer demand was 107.4 million tons, with 76.5% met by urea (FAO, 2020). Despite its widespread use, urea production contributes to environmental problems like greenhouse gas emissions, water and electricity consumption, and potential pollution (Fiamelda, 2022). Addressing these issues, researchers propose reducing urea demand through energy-efficient fertilizers (Bartolucci *et al.*, 2022). Conventional fertilizers, including urea, exhibit low efficiency (barely exceeding 30–35%), leading to environmental consequences from excessive application to meet crop nutrient needs (Kumar *et al.*, 2019,2022). Nutrient losses, through leaching (NO_3-) or gaseous emissions (NH_3 and N_2O), contribute to environmental pollution (Mahmud *et al.*, 2021). In response, stakeholders seek alternative nutrient sources, with nano-fertilizers emerging as potential game-changers in agriculture. However, comprehensive research on their benefits compared to conventional fertilizers remains limited (Verma *et al.*, 2022). 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). Formulations based on nanoclays enable extended nutrient release, while coating fertilizer molecules with nano-membranes allows for the development of controlled-release fertilizers (Guo *et al.*, 2018). 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

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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 (Kumar *et al.*, 2021). The functional nutrients primarily originate from urea, treated with non-ionic surfactants and stabilized in polymer matrices, forming nanoclusters below 100 nm. The adoption of nano-urea holds promise for sustainable agriculture practices, reducing agro-chemical use, minimizing environmental pollution, and enhancing soil health. 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.

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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. 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. 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. 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. The number of sprays and concentration are synchronized based on specific crop nitrogen requirements.

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Table 1. Specifications of IFFCO Nano Urea (Liquid) (FCO, 1985)

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S. No.	Parameters	Specifications
1.	Total nitrogen (% by wt.)	1-5 %
2.	Particle size in nanometer (nm) in one dimension (minimum 50 % of the material)	
	a) Physical particle size	20-50
	b) Hydrodynamic particle size	20-80

3.	Zeta potential in mV (+/- scale)	> 30
4.	Viscosity in cps	5-30
5.	pH	4.5-6.0

(Source: Kumar *et al*., 2021)

Nano urea (liquid) contain 4% N as encapsulated nitrogen analogues or forms embedded on an organic matrix. It has small size (20-50 nm); more surface area and number of particles per unit area than conventional urea (https://nanourea.in/).

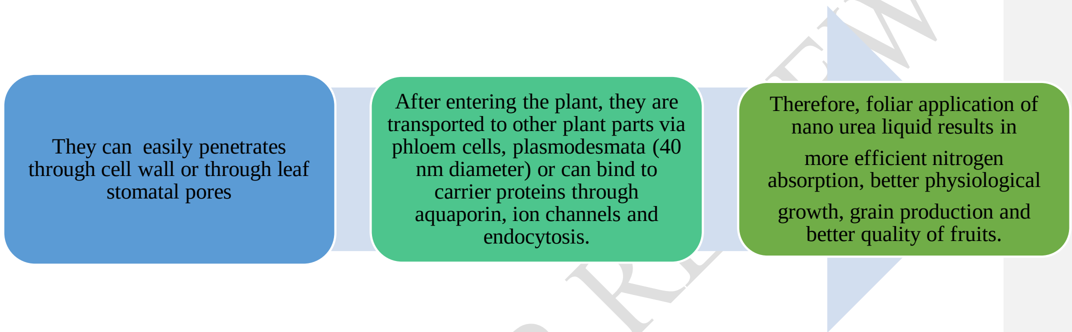

Figure 1: How nano urea works in plants

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. Its nitrogen content of 46%, cost-effectiveness, and rapid conversion to plant-available 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 (Lakshman *et al*., 2022).

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Properties of conventional urea

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. 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 top-dressing.

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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 (Table 2).

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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 (*Kumar et al*., 2019). This remarkable performance is attributed to nanotechnology, allowing the creation of extremely small particles with enhanced surface-to-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. The regulated delivery of nano urea ensures it achieves the desired impact on crops. Moreover, nano urea substantially reduces nitrogen loss during irrigation, enhancing overall nutrient utilization efficiency. This highlights the transformative potential of nanotechnology in optimizing fertilizer performance and mitigating environmental concerns associated with conventional urea application.

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Less environmental effect

Liquid nano urea not only proves cost-effective but also presents an environmentally friendly crop nutrition solution (Kumar *et al.,* 2021). Its reduced application requirement compared to conventional urea enhances crop nutrient efficiency, minimizing soil, water, and air pollution. Conventional urea often sees only 30-50% nitrogen utilization by plants (Subramanian *et al*., 2015; Kumar *et al.,* 2022), leading to 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

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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 (Kottegoda et al., 2011). 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.

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Table 2: Differences between liquid nano urea and conventional urea

Characteristics	Nano urea	Conventional urea
Year of Invention	2021	1823
Technology	Nano- technology	Conventional method
Particle size	32 nm	1 mm
Use efficiency (%)	85-90	30-40
Price (Rs.)	₹ 225/bottle (500 ml)	₹ 242/bag (45 kg)
Storage area requirement	Very less area	Very high area
Pollution	No	Air, water and soil
Vaporization	No	Yes
Soil residual	No	Yes
Effect on soil	Enhance quality	Acidifies soil
Availability in plant	Throughout the life cycle	3-4 days
Effect on crop maturity	Maturity on time	Early maturity
Intake medium	Direct through leaves	Through roots
Method of use	Only for foliar spray	Soil application as basal and top dressing and foliar spray

(Source: Lakshman *et al.*, 2022)

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 liquid 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. The controlled release of nutrients during the crop's growth phase minimizes wastage through leaching, allowing plants to absorb the maximum amount (El-Saadony*et al.*, 2021). 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.

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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.

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Cost-effective and improves farmers 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 (Kumar *et al*., 2020).Improves food quality and Sustainable Agriculture: Crops cultivated with Nano-urea are safe for consumption, showcasing enhanced food quality. 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.

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Fig. 2. Benefits of Nano urea (Source:https://nanourea.in/)

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

It is suggested to use liquid Nano urea solely for foliar application during the active growth stages of crops to fulfill their nitrogen needs.There is an additional labor cost associated with foliar application. The nanomaterials are very reactive because of their minute size with enhanced surface area (Konate *et al.*, 2018). 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 (Gothandam*et al.*, 2018), 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.

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The outcomes of field trials using Liquid Nano-Urea in major crops

Recommended doeFielddemonstrations 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. 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 (Kumar *et al*., 2021).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 nano-urea (2,500 mL/ha spray) + nano-Zn (1,250 mL/ha) sprays,

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Comment [UKS29]: Check the correct expression resulted in comparable grain yields (wheat, mustard, maize, and pearl millet) to 100% N + full P and K doses (Upadhyay *et al.*, 2023). 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 nano-urea sprays and 75% recommended N dose + 1 nano-urea spray (Sarkar *et al.*, 2023).

Table 3: Effect of liquid nano urea fertilizer on crops (Yogendra Kumar *et al.*, 2020aand 2020b)

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Crop	Parameters	Farmerfertilizer practice(100%NThrough conventionalurea)	FFP-50% N+Two sprays of Nano urea at critical stages of crop
Wheat (480)	Average yield (kg/ha)	4330	4580
	Response over FFP(kg/ha)		250
	Percent increase over FFP (%)		5.77
	Net return over FFP(₹ /ha)		4813
Maize (4)	Average yield (kg/ha)	4800	5150
	Response over FFP (kg/ha)		350
	Percent increase over FFP (%)		7.29
	Net return over FFP (₹ /ha)		6160
Chickpea (27)	Average yield (kg/ha)	1969	2133
	Response over FFP (kg/ha)		165
	Percent increase over FFP (%)		8.36
	Net return over FFP (₹ /ha)		8019
Mustard (70)	Average yield (kg/ha)	2650	2750
	Response over FFP (kg/ha)		100

	Percent increase over FFP (%)		3.77
	Net return over FFP (₹ /ha)		4425

Note: (Data in parenthesis are number of trials)

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.

Recommendations for Future Research

Nano-urea is in its early stages of implementation, presenting an opportunity for strategic promotion. For instance, a suggested approach involves using 75% nitrogen as basal through conventional urea,+ 1 spray. Alternatively, a 50% application through conventional urea plus 1, 2, or 3 additional sprays can be explored. Further testing across a variety of crops is essential to identify those most suited to nano-urea application. Current strategic research trials indicate the potential of Liquid Nano-Urea to enhance crop yields while minimizing environmental impact. However, comprehensive field trials and laboratory testing are imperative to ensure efficacy, biosafety, and bio-toxicity. Additionally, understanding the

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nutrient status in crops and identifying sources of nitrogen, whether from soil or the atmosphere, requires further study.Currently, most results are from one-season farmers' field trials, which may not be fully reliable. Therefore, it is crucial to carry out field trials for multiple seasons or cropping systems mode at ICAR and university research stations, under the supervision of scientific experts, to obtain valid and dependable results. Additionally, further validation is needed to determine whether Liquid Nano-Urea can serve as a substitute or supplement for conventional urea, effectively increasing nitrogen use efficiency and crop yields.

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