

Can Nano-Urea Serve as a Substitute for Conventional Urea Fertilizer?

Mummasani Asritha^{1*}, Sweetha V¹, Kotresh D.J.², Lokeshwar Kesamreddy¹, Sai Kumar Banoth¹,
Mohammed Shahid.S³

Abstract: -

High-yield agriculture depends on nitrogen fertilizers, and the most widely used N source globally has been conventional urea (46% N). However, its efficiency and environmental impact are low, which has motivated the search for alternatives. Nano-urea is a novel foliar fertilizer whose nitrogen particles are nanoscale, leading to a gold rush to improve surface area and absorption. Recent experiments indicate that foliar sprays of nano-urea can preserve or even increase crop yields and reduce the total amount of nitrogen applied. Despite these gains, the existing evidence suggests that nano-urea has not yet completely replaced conventional urea. Rather, it works best when combined with a smaller dose of basal fertiliser. It requires further research and field validation to maximise its utility.

Why Urea Matters So Much in Agriculture?

Nitrogen is an essential nutrient that promotes plant growth, and chemical fertilisers are important in contemporary agriculture because they are the primary means of supplying nitrogen (Tripathi et al., 2023; Upadhyay et al., 2023). Urea fertiliser has been widely used because of its high nitrogen content and low price. It contains 46 percent nitrogen. Urea supplies most of the nitrogen

fertiliser requirements worldwide. For

example, in 2019-20, approximately 76.5 per cent of global nitrogen fertiliser was urea, and global demand increased from 147.5 million tons in 2009 to 178.3 million tons in 2019 (Upadhyay et al., 2023). The popularity of this use indicates the value of urea in high crop production. Indian farmers use colossal quantities of urea: 106.8 million tons of grain on 30.5 million hectares of wheat alone,

Mummasani Asritha^{1*}, Sweetha V¹, Kotresh D.J.², Lokeshwar Kesamreddy¹, Sai Kumar Banoth¹, Mohammed Shahid.S³

¹Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu

²Department of Agronomy, University of Agricultural Sciences, Bengaluru

³Department of Agronomy, IARI academic hub CICR -Nagpur

indicating that nitrogen is the primary nutrient in these commodities (Tripathi et al., 2023). Urea is typically subsidised by the government, which is why it is a strategic component of food security. Therefore, a substantial increase in nitrogen efficiency, e.g., through nano-urea, may yield substantial productivity and sustainability benefits.

The Problem with Conventional Urea

Although it may be useful, conventional urea has severe shortcomings. In practice, crops never use most of the applied nitrogen. Traditional fertilizers are rarely reported to have nitrogen use efficiency greater than 30-35 per cent, and the NUE of urea in most soils is only 20-50 per cent, with this figure decreasing further at higher application rates due to losses (Tripathi et al., 2023). These losses can occur through nitrate leaching into water, ammonia volatilisation, or nitrous oxide emission. Not only do such inefficiencies waste fertilizer, but they also pollute. Urea manufacturing is also energy-intensive, as producing 1 kg of urea emits approximately 5.15 kg of CO₂-Eq (Upadhyay et al., 2023). In 2019, global urea production emitted approximately 918 million tons of CO₂ equivalent (Upadhyay et al., 2023). Excessive urea applications in the field have led to elevated nitrate concentrations in groundwater and increased nitrous oxide emissions. For example, 46-66% of applied

nitrogen has been found to leach in some soils (Tripathi et al., 2023). Such effects have raised environmental and economic concerns. An examination of fertiliser records indicates that conventional urea contributes to global warming, ozone depletion, and water pollution (Kumar et al., 2023). These concerns explain why the efficiency and side effects of nitrogen solutions require improvement.

What is Nano-Urea?

Nano-urea is a fertiliser produced via nanotechnology that forms tiny nitrogen particles. In nano-urea, each particle is typically 18 to 30 nm in size (Singh et al., 2026). For example, IFFCO's nano-urea product comprises nitrogen clusters smaller than 100 nm, held in place by a polymer (Upadhyay et al., 2023). Each droplet of nano-urea can contain tens of thousands of nitrogen atoms, yet a 1 mm prill of conventional urea has much less surface area. Because nano-urea is typically applied as a liquid spray, it does not replace soil-applied fertilizer; rather, it enriches it with finely dispersed nutrients. Users refer to it as liquid nano urea (LNU) and note that it provides significant coverage with small bottle sizes, e.g., 500 mL (Hasan et al., 2024). According to its proponents, liquid nano-urea offers several benefits, including a long shelf life and transportability compared with bulk granules (Hasan et al., 2024). In conclusion, nano-urea is simply urea reduced

to the nanoscale and applied as a foliar spray to ensure the highest possible uptake.

How Does Nano-Urea Work?

The most important features of nano-urea are its small particle size and controlled release. Particles of nano-urea (20-50 nm) have thousands of times more surface area than a grain of equal weight (Hasan et al., 2024; Singh et al., 2026). The nanoparticles may penetrate leaves when sprayed onto the cuticle, using stomata or leaf pores (Hasan et al., 2024). Afterward, they move through the phloem of the plant and through plasmodesmata to the growing areas. Studies indicate that these particles bind to transport proteins and gradually release nitrogen internally (Hasan et al., 2024). This controlled release minimizes nutrient waste: one review states that nano-urea release is controlled, thereby reducing environmental waste (Hasan et al., 2024). Nano-urea is absorbed gradually, unlike regular urea, which may be washed away or evaporate, so plants have more N available. The outcome is improved metabolic performance and development: nano-urea treatment has been found to increase photosynthetic area and root expansion, thereby increasing yield (Hasan et al., 2024). In short, nano-urea is effective because it penetrates plants more easily and releases nitrogen more gradually than regular urea, thereby enhancing nutrient uptake.

Potential Advantages of Nano-Urea

Advocates of nano-urea report several benefits. Nano-urea can greatly enhance nitrogen use efficiency (NUE) by increasing nitrogen uptake. Some statistics indicate that nano-urea can achieve an NUE of 80-90%, compared with just 30-40% for conventional urea (Hasan et al., 2024). This means that the crop takes up a larger portion of the applied N. As a result, farmers often reduce fertilizer costs. Field trials suggest that adding nano-urea sprays can enable one to reduce conventional N by 25-50% without reducing yield (Singh et al., 2026; Tripathi et al., 2023). Numerous studies have reported slight yield increases when nano-urea is supplemented during normal fertilization. For example, a multi-site wheat trial in India found that 2 nano-urea sprays at the recommended N dose increased grain yield by 6-9% compared with the recommended N spray alone (Tripathi et al., 2023). Statistically, 75% of the normal N plus a nano-urea spray produced the same yield as 100% N (Singh et al., 2026; Tripathi et al., 2023). Analyses estimate that adopting nano-urea in India would reduce N use by 1.0 billion kg, resulting in CO₂-equivalent emissions reductions of approximately 5.06 billion kg per year (Tripathi et al., 2023). Moreover, studies report quality improvements: a nano-urea spray was shown to promote grain protein and nutrient uptake in

pearl millet (Patel et al., 2024). Farmers will also benefit economically through higher returns from reduced urea use, which lowers costs (Kumar et al., 2023). Lastly, nano-urea is said to be environmentally safe and less polluting in the air and in water (Hasan et al., 2024). In summary, nano-urea may offer many benefits, including high NUE, reduced N runoff or losses, decreased greenhouse gas emissions, equivalent or higher yields with reduced fertilizer use, and cost savings.

What Do Field Studies Say?

Nano-urea is also being tested empirically on major crops. Field experiments generally indicate that nano-urea can maintain lower N yields in wheat. For example, a study of wheat across 21 locations in India concluded that applying two nano-urea sprays at 75% of the recommended N amount increased yield by 5-9% more than applying the full recommended amount (Tripathi et al., 2023). Notably, the nano-urea treatment containing 75% of the recommended N produced results statistically equivalent to the 100% N treatment (Tripathi et al., 2023). A second wheat experiment using two foliar nano-urea sprays and 75% basal N yielded grain yields equivalent to 100% N (Upadhyay et al., 2023). With maize, the results are more varied. A maize experiment found that 75% N plus a nano-urea spray produced more grain yield (8636 kg/ha) than 75% N alone (4502

kg/ha), though conventional foliar urea at 1% produced more (6415 kg/ha) (Poomalai et al., 2025). Generally, research by (Upadhyay et al., 2023) observed that 75% recommended N with nano-urea gave significantly better energy and yields compared with 50% recommended N with nano-urea. Multi-location experiments on various crops showed that nano-urea could increase yields in wheat, maize, and mustard across locations (Upadhyay et al., 2023). A recent study also shows that a hybrid regime of 50% basal N and nano-urea yielded results similar to 75% basal N and another nano-product, though it remained less than full N (Singh et al., 2026). Field research indicates that nano-urea would conserve more traditional N, yet it is not often superior to a complete-rate regime of prilled urea. There is an agreement that nano-urea is a useful supplement because it enhances nitrogen utilization, which in many cases results in a 25-50 percent decrease in the quantity of urea used without the loss of yield.

Limitations and Concerns

Nano-urea is promising but not without limitations. It is also fundamentally different from traditional fertilizer, which is applied to soil rather than foliarly sprayed (Krishna et al., 2025). This means it cannot fully replace the roles of bulk urea, which soils require as a basal nutrient supplement to support crops. Foliar spraying requires additional labor or

equipment costs, unlike merely sprinkling granules (Khontiang et al., 2025). Production and supply are also issues, as there are only a small number of manufacturers of nano-urea at the moment, and production is low. The nitrogen price per unit might be higher, which will put resource-disadvantaged farmers off (Stojanova et al., 2025). Most importantly, questions about long-term safety remain unanswered. Nanoparticles in the environment could affect soil microbiota or linger in the ecosystem; there is still no thorough research on residues and ecological effects. Most studies on nano-urea are short-term or plot-level. One review notes that there is a lack of systematic investigation into large-scale nano-fertilizers (Upadhyay et al., 2023). Regulatory and perception problems also persist: farmers might not be willing to use a new technology, and governments still do not provide clear rules for using nano-fertilizers (Stojanova et al., 2025). Taken together, these aspects indicate that despite the benefits of nano-urea, the technology has practical challenges and uncertainties. One review is blunt in saying that, at this point in time, nano-urea cannot entirely replace basal nitrogen, meaning it must be used as a complement rather than a replacement for conventional urea (Singh et al., 2026).

Can It Fully Replace Conventional Urea?

According to available evidence, replacing traditional urea with nano-urea is not yet feasible. Nano-urea has not been tested in the field as a direct replacement for standard fertilizer and has been used almost exclusively in conjunction with a lower rate of standard fertilizer. For example, when conventional N is reduced by half or less and only nano-urea is used, yields are always lower than with a full N program (Singh et al., 2026; Upadhyay et al., 2023). Farmers can achieve yields comparable to those realized with full N fertilization only by retaining 75-100% of the basal fertilizer and using nano-urea (Singh et al., 2026; Tripathi et al., 2023). Realistically, nano-urea appears capable of reducing urea consumption by 25 per cent without yield losses, but it cannot meet all the N plants demand (Tripathi et al., 2023; Upadhyay et al., 2023). Specialists note that nano-urea should be considered an efficiency enhancer, not a substitute. One study concludes that nano-urea cannot fully replace basal nitrogen but can supplement it, supporting quality development and reducing potential nitrogen losses (Singh et al., 2026). In conclusion, nano-urea cannot fully replace conventional urea, though its use can significantly reduce urea consumption. It is part of an integrated fertilization strategy, but not the only source of nitrogen.

The Way Forward

Nano-urea has a bright future based on ongoing research, development, and policy advocacy. Scientists suggest conducting additional field-scale experiments across a wider range of soils, climates, and crops to refine the use of nano-urea in nutrient management (Singh et al., 2026). This entails determining the optimal spray frequency and dosage and assessing long-term implications for soil health and crop quality. At the same time, efforts to increase production are crucial. Scholars are investigating ways to produce nano-nutrients at lower costs, which could increase adoption (Hasan et al., 2024). Policymakers and extension programs also need to communicate the use of nano-fertilizers and regulatory uncertainty to

farmers (Mim et al., 2025). Nano-urea may have significant environmental impacts if widely used as a supplement. For example, in wheat research, it was estimated that farmers would cut nitrogen fertilizer use by 25 percent, reduce emissions by approximately 5 billion kg/annum of CO₂-equivalent gas, and contribute to climate targets (Tripathi et al., 2023). Nano-urea could be a valuable climate-smart agricultural tool in combination with precise nutrient management and other more sustainable practices (Junior et al., 2025). In sum, nano-urea has sufficient potential for further development. It is unlikely to replace traditional urea in the near future completely, yet it can be very instrumental in enhancing nitrogen efficiency. The next stage of its



Conventional urea vs. Nano urea

Figure.1: Advantages and disadvantages of conventional urea vs. nano urea

potential realisation is careful research, investment in technology, and outreach to farmers.

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