

Nano Fertilizer: A Tiny Technology Transforming the Future of Indian Agriculture

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The global population explosion in recent decades has placed unprecedented pressure on the agricultural sector to increase crop yields dramatically. Historically, conventional chemical fertilizers (Urea, DAP, NPK) played a foundational role in achieving food security. However, heavy reliance on conventional inputs has turned into a double-edged sword.

Excessive and improper application of traditional fertilizers has led to:

- ❖ Severe Nutrient Losses: Up to 40–70% of applied Nitrogen, 80–90% of Phosphorus, and 50–90% of Potassium are lost to the environment via leaching, runoff, and volatilization.
- ❖ Soil & Ecosystem Degradation: Long-term over-application damages soil structure, disrupts microbial activity, depletes soil organic matter, and causes groundwater nitrate pollution.
- ❖ High Economic Burden: Low nutrient-use efficiency (NUE) translates to higher input and transportation costs for farmers alongside escalating government subsidy burdens.

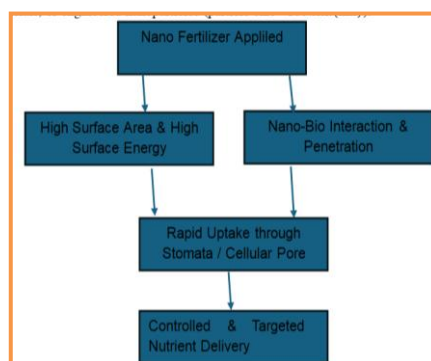
To bridge these gaps, **Nanotechnology** has emerged as a groundbreaking, sustainable solution capable of transforming nutrient management across the value chain.

The Historical Milestone: IFFCO's 2021 Breakthrough

- ❖ In mid-2021, Indian Farmers Fertilizer Cooperative Limited (IFFCO) introduced the world's first commercial Nano Urea Liquid.
- ❖ **Regulatory Inclusion:** It was officially approved and listed under the Fertilizer Control Order (FCO, 1985) by the Ministry of Agriculture & Farmers Welfare following extensive multi-location trials across Indian Agricultural Research Institutes (ICAR) and State Agriculture Universities.
- ❖ **Proprietary Innovation:** Developed indigenously at the Nano Biotechnology Research Centre (NBRC) in Kalol, Gujarat, a single 500 ml bottle of Nano Urea (containing 40,000 ppm nitrogen) effectively replaces at least one 45 kg bag of conventional solid urea.
- ❖ **Economic & Logistical Shift:** Beyond drastically reducing input costs for farmers by nearly 10–15%, the compact size dramatically slashes warehousing, handling, and transportation expenses while supporting national goals like Atmanirbhar Bharat.

Scientific Mechanism: Why Nano Fertilizers Superiorly Outperform

Nano fertilizers are synthesized or modified formulations of traditional nutrient salts, extracted organic materials, or engineered nanoparticles (particle size $<100\text{ nm}$).



Key Advantages over Conventional Fertilizers:

1. **Unmatched Surface Area-to-Volume Ratio:** The ultra-small size ($<100\text{nm}$) creates high surface reactivity, accelerating cellular nutrient uptake and supporting metabolic reactions inside the plant.
2. **Targeted & Controlled Release:** Nanostructured matrices (e.g., urea-impregnated zeolites or bio-polymer functionalized clusters) release nutrients gradually in response to environmental triggers and root exudates, reducing nutrient toxicity and environmental runoff.
3. **Enhanced Photosynthetic Activity:** Nanoparticles provide greater surface area within cellular sites, promoting chlorophyll synthesis, light absorption, and photosynthetic productivity.

Impact Analysis of Key Nano Micronutrients

Nano Nutrient	Cellular and Biological Mechanism	Observed Agronomic Benefits
Nano Nitrogen(N)	Rapid foliar absorption through leaf stomata; steady metabolic release.	Replaces bulk urea, prevents nitrogen leaching into groundwater, and increases overall Nutrient Use Efficiency (NUE) up to 45% or higher.
Nano Zinc (Zn)	Triggers essential enzymatic pathways; aids auxin synthesis and pollen function	Boosts chlorophyll content, rhizospheric microbial activity, acid/alkaline phosphatase, and phytase activity; protects plants during drought stress.
Nano Copper (Cu)	Nano Copper (Cu) rapidly penetrates cell membranes; moves from shoot to root tissues.	Enhances growth, though application concentrations require precise tuning to avoid phytotoxicity.
Titanium Dioxide (TiO ₂)	Stimulates photoreception systems in leaf cells.	Low-dose applications (0.25--4%) accelerate growth, nutrient absorption, and biomass production.

Integrating Nano Fertilizers with Smart Farming Technologies

Nano fertilizers deliver their maximum potential when combined with modern precision farming infrastructure.

PRECISION AGRONOMY MATRIX**1. Technology Integration**

- IoT & Soil Sensor
- Agricultural Drones
- Variable Rate Technology (VRT)
- AI & Remote Sensing (NDVI/SAVI)

2. Primary Operational Benefits

- Real-time soil nutrient tracking
- Precision Foliar nano spraying
- Site-specific variable delivery
- Crop stress & yield predictions

➤ **Drone-Based Ultra-Low Volume Spraying:** Spraying liquid nano fertilizers via agricultural drones minimizes manual labor, ensures uniform coverage on leaves, and reduces chemical wastage.

➤ **IoT & Sensor-Guided Application:** Real-time field sensors detect micro-nutrient deficiencies, allowing farmers to apply nano formulations strictly when crops express biological demand.

SIDE-BY-SIDE COMPARISON

A Revolution in Every Drop

1 Bag of Solid Urea (45 kg)



UREA
46% N
(45 KG)

Bulky & Heavy Transportation

Large Storage Space

Higher Nutrient Loss

More Environmental Impact

VS

1 Bottle of Nano Urea (500 ml)



NANO UREA LIQUID

Lightweight & Easy Transportation

Easy Storage, Space Saving

Higher Nutrient Use Efficiency

Eco-Friendly & Sustainable

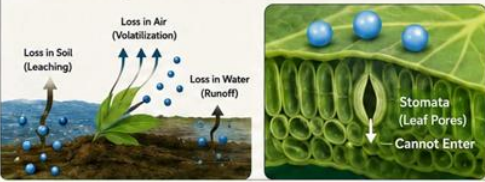
“A single 500 ml bottle of Nano Urea can replace a 45 kg bag of conventional urea, curbing environmental pollution and boosting nutrient efficiency.”

HOW NANO UREA WORKS IN PLANTS

Smarter Uptake, Better Results

- #### 1. Conventional Urea (Micro Size) – More Loss, Less Gain

Micro-sized particles are larger in size. They do not enter the leaf pores and get lost in the soil, water or air through volatilization, leaching and runoff.



Loss in Air (Volatilization)
Loss in Soil (Leaching)
Loss in Water (Runoff)
Stomata (Leaf Pores) Cannot Enter
- #### 2. Nano Urea (Nano Size) – More Uptake, Maximum Benefit

Nano-sized particles are extremely small. They easily penetrate the stomatal openings and are absorbed by the plant for better growth and yield.



Minimal Loss | Maximum Utilization
Enters Stomata & Gets Absorbed

Nano Urea – Small in Size, Big in Impact!

FARMER'S GUIDE

How to Use Nano Urea

Recommended Stage
Apply foliar spray during active crop growth stages (e.g., tillering/branching).

Dosage Rate
2 – 4 ml of Nano Urea per liter of clean water.



1 Liter Water → 2 – 4 ml Nano Urea

Best Practice
Combine with drone spraying or knapsack sprayers equipped with fine mist nozzles for optimal leaf coverage.



Key Tips

- Use clean water for mixing.
- Spray in the early morning or late evening.
- Avoid spraying before rain.
- Shake the bottle well before use.

Nano Urea – Innovation for a Sustainable Tomorrow

Source of Information: Indian Farmer Fertilizer Cooperative Limited (IFFCO), Nano Urea (liquid): Product information. Available from the official IFFCO website.

Current Challenges, Safety & Safety Protocols

Despite the clear benefits, widespread adoption requires addressing key concerns:

- **Ecotoxicology & Bio-Safety:** Long-term toxicity data regarding nanoparticle accumulation in soil microbiota, earthworms, and crop food chains must be systematically studied.
- **Crop Sensitivity Variations:** Studies show crops respond differently; for example, mung bean exhibits greater sensitivity to nano-copper toxicity than wheat.
- **Initial Awareness & Infrastructure:** Rural adoption requires digital literacy, structured farmer training programs, and affordable application equipment.

Conclusion & Future Outlook

Nano fertilizers represent a monumental leap forward for sustainable agriculture. By replacing bulky, inefficient traditional fertilizers with smart, targeted nanotechnology, India can achieve a greener, climate-resilient agricultural system. With continued long-term field evaluations, robust regulatory oversight, and smart-farming integration, nano fertilizers will serve as a core pillar of modern farm profitability and national food security.

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