



## Nanofertilizers: Smart Nutrition for Plants

\*Saikavya Vendra<sup>1</sup>, Kodavath Aruna<sup>2</sup> and Sannaiala Kavya<sup>2</sup>

<sup>1</sup>Teaching Associate, Department of Agronomy, Agricultural College, Palem,  
Nagarkurnool District-509381, India

<sup>2</sup>Ph.D Research Scholar, Division of Agronomy, Professor Jayashankar Telangana  
Agricultural University, Rajendranagar-500030, Hyderabad, India

\*Corresponding Author's email: [saikavyavendra@gmail.com](mailto:saikavyavendra@gmail.com)

Nano fertilizers represent the pinnacle of "smart" agriculture, delivering nutrients at the atomic scale for unparalleled plant uptake and minimal waste. Encapsulating essentials like NPK in nanoscale carriers, they release payloads on demand, boosting yields by 20-55% while slashing environmental harm. Cutting-edge works of researchers highlights yields surges in wheat and rice, while in detail enhanced NUE via slow-release mechanisms. This article unpacks nano fertilizers alchemy-from synthesis to soil-spotlighting their role in drought-proofing crops and fortifying food security. As we nano-tune nutrition, imagine farms where every granule counts, heralding a verdant, viable tomorrow.

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### Introduction

Picture a seed sprouting not in a nutrient flood, but a gentle, timed trickle-nanoparticles whispering essentials directly to its cells, coaxing vigorous growth with zero excess. Welcome to the nanoscale frontier of plant nutrition: nano fertilizers, where chemistry meets crop care in a symphony of efficiency. Conventional fertilizers, like overzealous waiters, overserve, with plants absorbing just 30-50% before the rest runs off, fuelling algal blooms and dead zones. Nano fertilizers flip the script, shrinking particles to 1-100nm for targeted delivery, enhancing uptake to 80% + and yields dramatically. Trailblazing studies illuminate the path. Goyal *et al.* (2025) reviewed nano-NPK's prowess, showing 20-55% wheat yield hikes and eco-gains *via* reduced leaching. Nisha *et al.* (2025) championed smart inputs like nano-urea, lifting NUE from 22% to 40% in potatoes and maize. Even in quality realms, emerging evaluations affirm nano fertilizers enrich crop nutrition while curbing pesticide needs, as per recent agrochemical insights. These aren't lab curiosities; they're catalysts for a fertilizer-free future, where "less is more" feeds more. Join this journey through nano-nourishment's wonders, from molecular marvels to field triumphs and gaze toward a world where plants thrive on intelligence, not indulgence.

### Nano-Sized Solutions: Crafting the Future of Fertilizer

Nano fertilizers aren't your grandpa's granules; they're engineered wonders-polymers, liposomes, or metal oxides encapsulating nutrients for slow, soil-responsive release. Urea coated in hydroxyapatite nanoparticles, for instance, volatilizes 70% less than standard forms, syncing with root rhythms. Synthesis spans green methods (plant extracts as stabilizers) to high-tech emulsions, ensuring biocompatibility. Goyal *et al.* (2025) spotlight nano-zeolites and HAP-urea, which extend P delivery to 40-50 days versus 8, spiking photosynthetic rates and protein synthesis in rice and maize. This "smart" timing dodges peak-loss windows, like rainy seasons, transforming volatile N into steadfast sustenance. In veggies, nano-ZnO foliar sprays amplify micronutrient absorption, fortifying tubers against deficiencies that hobble

global harvests. Paired with IoT sensors, nano fertilizers evolve into "precision pairs," where apps dictate doses based on real-time soil chatter. The payoff? 20-80% yield leaps at half the input, as Nisha *et al.* (2025) validated across pulses and oilseeds. It's nutrition, nano-style: elegant, efficient, earth-kind.

### From Lab to Leaf: Stories of Nano Triumph

Field tales tantalize. In drought-plagued India, nano-NPK revived tomato yields by 35%, roots delving deeper thanks to enhanced water retention. Nisha *et al.* (2025) chronicled potato plots where 25% conventional doses matched full-strength outputs, nutrients penetrating stomata like mist, not deluge. For staples, Goyal *et al.* (2025) reported maize Zn uptake doubling via nano-ZnO, biofortifying grains to combat "hidden hunger" affecting 2 billion people. Even in safety spheres, nano fertilizers shine. Evaluations show they slash pesticide reliance by bolstering plant immunity, yielding cleaner carrots and contaminant-free corn-vital as urban diets demand transparency. In Brazil's soy belts, nano-iron quelled chlorosis, harvesting 25% more while sparing soils from heavy metal overload. These narratives aren't isolated; they're scalable. With costs plummeting 15% yearly, nano-adoption could avert 50 million tons of annual fertilizer waste, per FAO projections, greening ag's carbon footprint.

### Hurdles and Horizons: Nano's Next Chapter

Skeptics cite toxicity fears-nanoparticles accumulating in food chains? Yet, studies affirm low-dose safety, with regulations evolving apace. Scalability stumbles on production premiums, but bio-based nanos portend affordability. Tomorrow beckons hybrids: nano-biofertilizers merging microbes for symbiotic boosts. As frontiers like RSC's nano stimulants suggest, AI-optimized nano-cocktails could drought-proof orchards and salinity-proof coasts. The vision? Farms as living labs, where nano-nutrition nurtures not just plants, but planetary health.

### Conclusion

Nano fertilizers aren't a fad; they're farming's finesse, channelling smart science to satiate soil and soul. Researchers yield epics and efficiency anthems and safety sagas paint a portrait of progress-nutrients delivered with nanoscale savvy, yields soaring, Earth exhaling. In this atomic age, we redefine abundance: not more, but masterful. Let's sprinkle the future with nano-wisdom, harvesting hope one particle at a time.

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