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Study Of Novel Fertilizers to Enhance Crop Productivity and Environmental Sustainability: A Review

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Abstract
Declining nutrient use efficiency and rising environmental concerns due to excessive use of conventional fertilizers have created an urgent need for sustainable alternatives. Novel fertilizers, including Nano-fertilizer, controlled- release fertilizers and bio formulations are emerging crop productivity while reducing ecological damage.
The present study reviews recent research papers and reports to understand the role of novel fertilizers in improving crop yield, nutrient uptake and soil health. Finding from literature indicate that Nano-fertilizer can increase nitrogen use efficiency by 20-30% and reduce Leaching losses significantly compared to conventional urea. It can be concluded that novel fertilizers hold strong potential for achieving higher crop productivity along with environmental sustainability. Studies also highlight benefits such as reduced green house gas emission and Improves microbial activity in soil. However, issues related to cost, large- scale production and long- term ecological safety still require further research before widespread adoption.
Keywords: Nano-fertilizer; Sustainability; Conventional fertilizer; Footprints; Leaching; Nutrient Use Efficiency

Introduction

Agriculture faces the dual challenges of feeding a growing global population while minimize environmental degradation. Conventional fertilizers, particularly urea, have played a pivotal role in achieving food security since the Green Revolution. However, their excessive and imbalanced use had led to alarmingly low nutrient use efficiency of Urea rarely exceed 30-35 with remaining 65-70% lost through Volatilization, Leaching and denitrification.(Raza et al 2021). These losses not only cause economic losses to farmers but also contribute to ground water nitrate pollution, eutrophication of water bodies and emission of nitrous oxide (N2O), a greenhouse gas 298 times more potent than CO2. To address these issues, the concept if “novel fertilizer” has gained attention in the last decade. The unique properties of Nano particles high surface are to volume ratio, controlled release behaviour and targeted delivery- allow them to supply nutrients more efficiently to plant compared to bulk conventional fertilizers. Several studies in the past five years have demonstrated that nano urea, nano Zinc and nano phosphorus can enhance crop productivity with 25-30% lower nutrient doses.

Nano-fertilizer Improve soil microbial activity and reduce the carbon footprints of agriculture, aligning with the goals of climate-smart farmer awareness, lack of standardized application protocols and concerns regarding the long- term fate of nanoparticles in soil ecosystem. Therefore, the current status, benefits, limitations and future prospect or Nano-fertilizer for enhancing crop productivity and environmental sustainability.

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Material and Methods

The present study is a review based on recent research papers and reports concerning novel fertilizers, with particular emphasis on nano-fertilizers. The literature was examined to understand their effects on crop yield, nutrient uptake, soil health, nutrient-use efficiency and environmental sustainability. Reported findings on fertilizer dose reduction, crop response, nutrient losses, greenhouse-gas emissions, carbon footprint, limitations and adoption challenges were organized and discussed to identify the potential and future scope of novel fertilizers.

Results and Discussion

Types of Nano-Fertilizers

Type of Nano-fertilizers – Based on composition and mode of action, nano fertilizers reported in the literature can be broadly classified into three categories.

Macronutrient Nano fertilizers – These nano formulations supply primary nutrients like nitrogen, phosphorus and potassium. The most widely studies example – nano urea.

In nano urea, molecules are coated or adsorbed into nano particles of size 20-50cm, which enables slow and sustainable release of nitrogen in the rhizosphere (Kumar et al; 2024).

Micronutrient Nano-fertilizer – Micronutrient like Zinc, Iron, Copper and manganese have very low use efficiency of 2-5% when applied through conventional source. Nano form of these nutrients such as nano Zinc oxide (nZnO) and nano Iron oxide (nFe2O3) smaller size and higher uptake due to smaller and higher reactivity. (Dimkpa et al. 2020).

Nano Bio- fertilizers /Nano composite fertilizers- This is the newest category where nano material are combined with beneficial microbes or organic carriers. Ex- including nano-Chitosan loaded with NPK, nano- zeolite carrying rhizobium and carbon based nano fertilizers.

Impact of Nano-fertilizer on Crop Productivity

A large number of studies conducted during 2019-2025 have evaluated nano fertilizers on major cereals, pulses and vegetable crops. The overall trend from literature indicates that nano fertilizers can sustain or increase crop yield while reducing the recommended dose of conventional fertilizers by 25-50%.

Effect on cereal crops- Wheat and rice are the most tested crops. In rice, Kumar et al. (2022) reported a 4.8% yield increase with nano DAP 75% RDP compared to 100% RDP. The yield advantages is mainly due to better nitrogen uptake during critical growth stages are reduced ammonia loss.

Effect on micronutrient uptake and quality- Nano forms of Zinc and iron have shown significant improvement in grain nutrient content, which is important for addressing hidden hunger.

Key observation from literature-

Dose reduction- Most studies confirm 25-50% saving in N and P without yield loss.
Application stage matters- Foliar spray at active growth stages like tillering, flowering gives best results.

Combination works better – Nano-fertilizer +50-75% conventional gives more stable yield than 100% replacement with nano alone.

Role of Nano-fertilizer in Environmental Sustainability

The excessive use of conventional fertilizers is a major source of pollution in agro-ecosystem. Nano-fertilizer are reported to migrate several environmental problem due to their higher nutrient use efficiency and controlled- release properties.

Reduction in nutrient losses

The biggest environmental issues with urea is ammonia volatilization and nitrate leaching, which can be 40 to 70% of applied N. Because nano urea release nitrogen slowly and is taken up faster through leaves, losses are significantly reduced

Migration of greenhouse gas emissions -

Agriculture contributes approximately 10% of total anthropogenic N2O emissions, mostly from denitrification of excess nitrate. A 2- year study IGP region reported that nano urea plus 50% RDN reduced seasonal N2O flux by 19.6% compared to 100% RND without yield penalty (Yadav et al 2023). This is important for meeting India's climate commitments under NDCs.

Lower carbon footprint-

500 ml bottle of IFCO nano urea is equivalent to one 45 kg bag of urea in nitrogen content. This reduce transportation, storage and application cost drastically.

Challenges and Limitation

Despite potential benefits, large-scale adoption of nano fertiliser faces key challenges:
High cost and low affordability: Synthesis needs advanced tech, making nano Zn/ Fe 3-5 times costlier than work salts. For 86% marginal farmers in India it remains uneconomical without subsidy(Kah et al., 2021).

Lack of Standard protocol : No crop- soil- region specific doses exist yet (Raliya et al., 2021). Overdose can cause toxicity, while under dose gives no benefit. Farmers often confuse it with pesticides.

Low farmer awareness: >70% farmers in UP/Bihar are unaware of correct usage (Singh et al., 2024). Trust deficit exist as yield impact is not instantly visible.

Note: Govt. and IFFCO are addressing these through demos, training and new 2020 nano- guidelines. However, policy support is needed for mass adoption.

Environmental Benefits of Nano Fertilisers Reported in Literature

Environmental Parameter	Conventional Fertilizer	With Nano fetilizer	% Improve r
NH3 Volatilization	35-40% of applied N	23-28% of applied N	28-34% reduce
NO3 Leaching	25-30% kg/ha/season	17-23kg/ ha/season	22-30%reduce
N20 Emission	1.2- 1.5kg NZO-N/h	0.9-1.2 kg N20-N/ha	19.6% reduce
PRunoff Loss	8-12% of applied P	4-7% of applied P	~40% reduce

Conclusion

This review shows that nano fertilizers offer a smart alternative to conventional fertilizers. Studies confirms they can cut fertiliser doses by 25 - 50% while maintaining or improving yield in rice ,et and other crops. There high efficiency lower environ Rental losses and reduced bulk volume make them sustainable for climate smart agriculture star 500 ml naino urea can replace a 55 kg urea bag redo Using into Amazon and transport costs however challenges like high cost lack of standard doses poor farmer awareness and limit Long term safety data restriction de

Future Scope

Long-term Trials- Conduct 5-10 years multi – location studies on soil health and residual effects.

Nano-Bio integration- Explore nano fertilizers +beneficial microbes for synergistic benefits.

Safety studies- Access Nanoparticles transfer in food chain and set more MRL standards. Policy support- Provide subsidy and farmer training for wider adoption.

Note: Nano fertilizers can make farming more productive and sustainable but success needs joint effort from research, industry and policy.

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