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Enhancing agronomic crop performance: a review of the role of Nano-Diammonium Phosphate (Nano-DAP) in improving soil nutrient status and crop productivity

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ABSTRACT

Nano-diammonium phosphate (Nano-DAP) is a promising source of nitrogen (N) and phosphorus (P_2O_5) for crops and provides an effective remedy for nutrient deficiencies in standing plants. This review highlights the critical role of phosphorus in plant growth and examines the limitations of conventional fertilizers such as urea, DAP, and compost, which, although essential for crop production, often suffer from low nutrient use efficiency and contribute to environmental pollution. Drawing on a synthesis of published studies, this review demonstrates that Nano-DAP enhances phosphorus solubility and availability in soil–plant systems, thereby improving nutrient absorption, stimulating plant growth, and increasing crop yields compared to conventional fertilizers. The review also evaluates the impact of Nano-DAP on yield performance, nutrient uptake, and its application in major field crops. Furthermore, the advantages and potential limitations of Nano-DAP are discussed in the context of sustainable agriculture. Overall, the use of nano-fertilizers, particularly Nano-DAP, presents a promising strategy to improve agricultural productivity while reducing environmental risks.

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1. INTRODUCTION

Fertilizer application plays a vital role in enhancing the growth and yield of agronomic crops (Babu et al., 2021). The choice of fertilizer type and dosage is critical to ensure that crops receive adequate nutrition. This choice is influenced by several factors, including soil characteristics, crop rotation practices, and existing nutrient deficiencies. Agronomic crops require essential macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) for optimal growth and development. Nitrogen promotes vigorous vegetative growth and increases the protein content of grains. Phosphorus supports root development and seed formation, whereas potassium contributes to improved water uptake and disease resistance (Muktamar et al., 2020). However, the application of commonly used inorganic fertilizers such as urea, diammonium phosphate (DAP), and muriate of potash (MOP) often results in low nutrient-use efficiency due to significant losses through leaching, volatilization, and denitrification (Chinnamuthu & Boopathi, 2009).

For decades, chemical fertilizers have been extensively used in agriculture to supply essential nutrients for crop growth and productivity. However, their continuous application raises environmental concerns and health risks for users. Excessive and inefficient use of conventional fertilizers has been linked to soil degradation, nutrient leaching, and water pollution (Rakshit et al., 2020). In recent years, nano-fertilizers such as nano-urea and nano-DAP have emerged as

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promising alternatives to conventional fertilizers, offering several agronomic and environmental benefits (Kumar et al., 2025). Due to their extremely small particle size and high surface area, nano-fertilizers release nutrients in a controlled manner, allowing gradual absorption by plants. This improves nutrient uptake efficiency, reduces losses, and enhances processes such as seed germination, photosynthesis, nitrogen assimilation, and the biosynthesis of proteins and carbohydrates (Meena et al., 2024). Consequently, crops treated with nano-fertilizers often show stronger growth, greater stress tolerance, and higher yields compared to those treated with conventional fertilizers. Additionally, the smaller required doses of nano-fertilizers reduce transportation costs and minimize environmental burdens (Kumar & Dahiya, 2024).

Nanotechnology therefore holds great potential for addressing the limitations of traditional fertilization practices (Mim et al., 2025). Nano-fertilizers can supply nutrients in a controlled and sustained manner, aligning with the physiological needs of crops and supporting long-term soil health and sustainability (Tarafdar et al., 2014). Table 1 presents data on the consumption of total nitrogen (N), phosphorus (P), and potassium (K) (in thousand tons) from 2016–17 to 2021–22 (EPWRF India Time Series, 2023).

Although Nano-DAP shows significant promise in improving nutrient uptake and crop productivity, several critical research gaps remain. In particular, the precise mechanisms by which Nano-DAP interacts with plant roots, soil microbes, and nutrient availability require further clarification. Moreover, while short-term benefits of Nano-DAP have been reported, its long-term effects on soil health, microbial populations, and nutrient cycling are still uncertain. Comprehensive environmental impact assessments are also required to evaluate potential risks, including nanoparticle toxicity, soil interactions, water solubility, and environmental fate (Soni et al., 2024). Research is also lacking on the optimization of Nano-DAP formulations tailored to specific crop species and soil conditions. The performance of nanoparticles depends on factors such as size, shape, and surface chemistry, but the most effective combinations for agricultural use remain underexplored.

Since most studies to date have been conducted under laboratory or controlled conditions, field-based trials are essential to determine the real-world effects of Nano-DAP on yield, quality, and economic viability (Ijaz et al., 2024). Furthermore, the increasing use of Nano-DAP underscores the need for robust regulatory frameworks and guidelines to ensure its safe application (Kekeli et al., 2025). In this regard, developing standardized protocols for synthesis, application, and regulation is crucial to support safe and effective adoption of Nano-DAP in agriculture (Basavegowda & Baek, 2021).

The main objective of this review is to summarize and analyze current research on Nano-DAP, with emphasis on its potential to enhance crop growth, nutrient-use efficiency, and environmental sustainability. The review also aims to highlight its benefits over conventional fertilizers, identify research gaps, and discuss future perspectives for its application in sustainable farming systems. In addition, it seeks to clarify mechanisms of action, assess potential environmental risks, and advocate for field validation and regulatory development to facilitate safe and effective use of Nano-DAP in agriculture.

2. Nano-DAP

Nano-diammonium phosphate (Nano-DAP) is an efficient source of nitrogen (N) and phosphorus (P_2O_5), two essential macronutrients required for optimal crop growth and productivity. It was developed to address nitrogen and phosphorus deficiencies in standing crops and is suitable for diverse agronomic applications. The Nano-DAP formulation typically contains 8.0% nitrogen and 16.0% phosphorus (as P_2O_5) in liquid form (Shete et al., 2024).

Due to its nanoscale particle size (<100 nm), Nano-DAP has a higher surface-area-to-volume ratio compared to conventional formulations, which improves solubility, absorption, and internal mobility within plant tissues. The ultra-small particle size enables Nano-DAP to penetrate plants through natural openings such as stomata, seed surface pores, and other microstructures, facilitating faster and more efficient nutrient uptake (El-Ghany et al., 2021).

The nitrogen and phosphorus nanoclusters in Nano-DAP are stabilized and functionalized with biopolymers, enhancing nutrient bioavailability and reducing premature losses. This targeted nutrient delivery mechanism contributes to improved seed vigor, higher chlorophyll content, greater photosynthetic efficiency, superior seed quality, and ultimately increased crop yield.

Moreover, Nano-DAP is characterized by high nutrient-use efficiency and precision, minimizing nutrient losses through leaching or volatilization and thereby reducing the environmental footprint compared with conventional fertilizers (Poudel et al., 2023). Unlike traditional bulk fertilizers, Nano-DAP provides precise and targeted nutrient delivery that meets plant requirements while lowering the risk of adverse environmental impacts.

Nano-DAP is currently produced under the supervision of the Indian Farmers Fertilizer Cooperative Limited (IFFCO), a pioneer in the promotion of nano-fertilizer technology to support sustainable agriculture in India (IFFCO, 2022). As illustrated in Figure 1, Nano-DAP particles generally exhibit spherical to irregular morphologies with high surface area, which further enhances solubility and nutrient release efficiency.

3. Review of Literature

3.1. Nano-DAP effect on crop growth and yield

At Dr. C.V. Raman University, Madhya Pradesh, an experiment on wheat demonstrated that treatments with 100% NPK supplemented by Nano-DAP significantly improved yield attributes. These included a higher number of tillers, more grains per earhead, longer earhead length, more spikelets per earhead, and an overall increase in yield per hectare (Tomar et al., 2024).

Similarly, a study conducted at B.A. College of Agriculture, Anand Agricultural University (AAU), Anand, showed that combining 75% of the Recommended Dose of Fertilizer (RDF) N and P with foliar spray of Nano-DAP (4 ml L^{-1} at 25 DAS), or 50% RDF N and P + seed treatment with Nano-DAP (5 ml kg^{-1} seed) + foliar spray at 25 DAS, produced significantly higher yields compared with other treatments (Parmar et al., 2024). A summary of these and related studies on the effect of Nano-fertilizers on crop growth and yield is presented in Table 2.

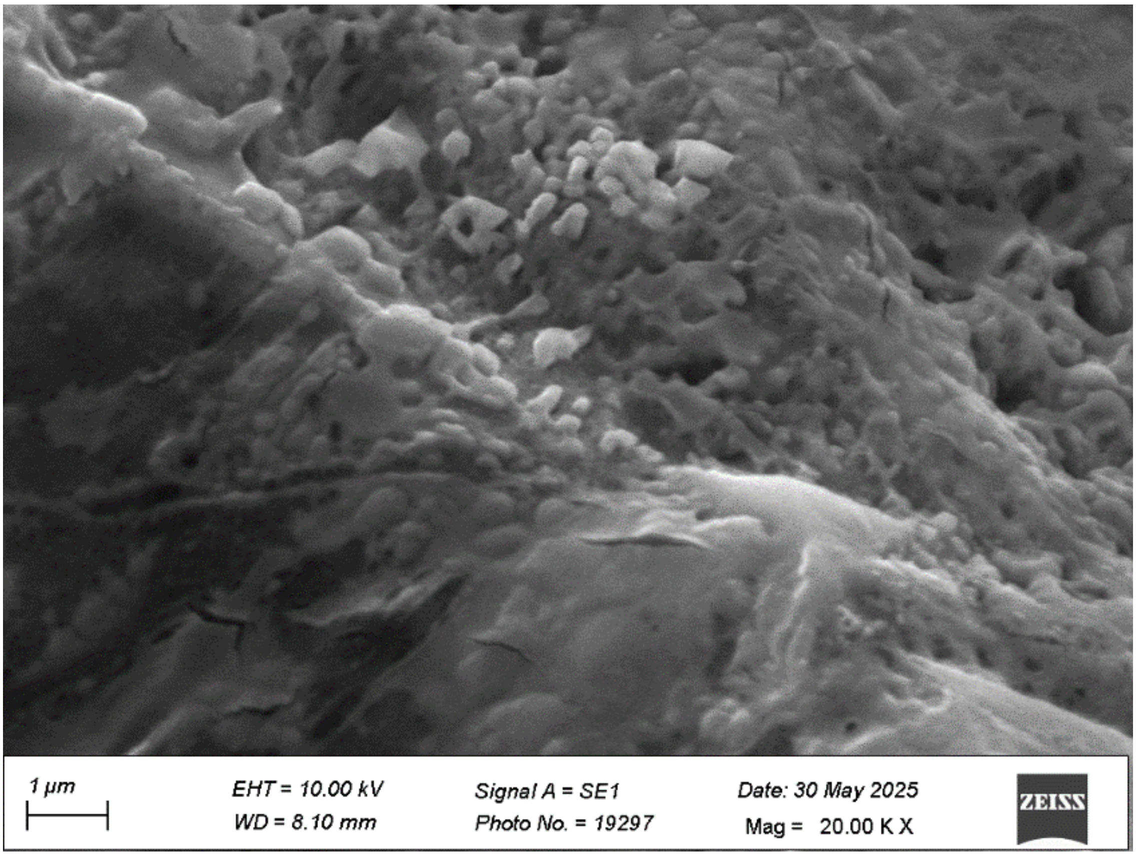
Table 1. Fertilizer consumption (N, P, K) across Indian States (2016–17 to 2021–22)

States	Year					
	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
Andhra Pradesh	1686.96	1564.02	1559.08	1683.03	2025.94	1699.58
Arunachal Pradesh	0.00	0.00	0.00	0.00	0.00	0.00
Assam	230.97	251.88	316.27	278.33	279.62	261.61
Bihar	1508.57	1657.57	1676.34	1820.5	1910.96	1613.46
Chhattisgarh	673.35	550.46	722.75	737.35	871.61	758.01
Gujarat	1604.45	1841.57	1546.92	1791.67	1957.41	1699.84
Haryana	1342.85	1375.75	1438.04	1410.45	1464.67	1374
Himachal Pradesh	56.49	57.57	56.28	58.62	59.26	55.99
Jammu and Kashmir	116.66	134.68	108.47	78.84	180.5	120.07
Jharkhand	148.94	177.78	171.24	181.67	208.15	201.82
Karnataka	1628.22	1595.28	1734.18	1860.91	2222.84	2192.38
Kerala	180.42	241.98	158.34	174.87	201.11	166.1
Madhya Pradesh	1981.9	2015.93	2621.14	2683.39	2893.51	2651.73
Maharashtra	2806.13	2943.54	2788.68	2941.29	3413.6	3135.57
Manipur	12.56	20.66	11.73	17.5	14.88	12.38
Meghalaya	0.00	0.00	0.00	0.00	0.00	0.00
Mizoram	2.92	4.7	6.19	4.08	1.12	1.26
Nagaland	2.64	2.66	0.23	0	0.34	0.24
Odisha	494.34	536.93	507.98	574.38	611.19	587.38
Punjab	1818.54	1674.45	1875.94	1905.88	1933.25	1989.76
Rajasthan	1354.68	1203.96	1524.6	1717.58	1776.99	1611.39
Sikkim	0.00	0.00	0.00	0.00	0.00	0.00
Tamil Nadu	908.45	919.95	960.63	987.17	1120.9	1129.59
Telangana	1371.92	1391.74	1323.59	1479.18	1817.55	1636.42
Tripura	26.11	15.71	18.15	19.63	16.04	19.36
Uttar Pradesh	4261.11	4655	4476.08	5172.97	5628.99	5169.07
Uttarakhand	202.12	182.72	165.45	163.41	158.04	135.93
West Bengal	1502.03	1550.95	1494.31	1599.16	1737.61	1542.9
Andaman and Nicobar Islands	1.6	0.88	0.00	0.00	0.13	0.69
Chandigarh	0.00	0.00	0.00	0.00	0.00	0.00
Dadra and Nagar Haveli	1.17	0.51	0.19	0	0.88	0.42
Daman and Diu	0.16	0.14	0.00	0.00	0.00	0.00

Source: EPWRF India Time Series (2023)
Note: All values are in thousand tonnes ('000 tonnes); "0.00" indicates no recorded consumption.

Table 2. Research studies on the Nano DAP effect on the growth and yield of the crop

Author(s)	Location & Crop	Treatment Details	Key Findings
Attri et al. (2023)	SKUAST-Jammu (Kharif season, Paddy)	75% N, 100% P, 100% K - Seedling treatment: Nano DAP @ 5 ml L^{-1} - Foliar spray: Nano DAP @ 4 ml L^{-1}	Higher growth and yield were observed with the combined Nano DAP treatment.
Poudel et al. (2023)	Agriculture Research Farm, BHU, Varanasi, Uttar Pradesh, (Wheat)	100% N & K + 75% P - 2 foliar sprays of nano-P at tillering and panicle initiation stages	Yield increased by 37.1% compared to 100% RDF.
Singh et al. (2023)	CSAUA&T, Kanpur (Wheat crop)	75% NPK + Nano N & Nano P - Applied at 30 and 45 days after sowing	Plant height: 91.23 cm, Tillers: 322.5 m^{-2}, LAI: 0.83, Dry matter: 1532.7 g m^{-2}
Khati et al. (2024)	Research and Extension Center, Gaja (Kharif, Finger millet)	50% P (DAP) + 100% NK - Seed treatment: Nano DAP @ 5 ml kg^{-1} - 2 foliar sprays: Nano DAP @ 4 ml L^{-1} (at 30–35 & 45 days after germination)	Improved plant growth, seed yield, and seed quality with Nano DAP treatment compared to control.



Source: Division of Research & Innovation (DRI), Uttaranchal University, Dehradun, Uttarakhand

Figure 1. Scanning electron microscope (SEM) image of Nano DAP particles showing their nano-scale morphology and surface structure. The image reveals uniform, spherical to irregularly shaped nanoparticles with high surface area, which enhances their solubility and nutrient release efficiency compared to conventional DAP.

Deo et al. (2022), at S.G. College of Agriculture, Jagdalpur, Chhattisgarh, observed that applying 50% P + 100% NK + root dipping (Nano-DAP (5 ml kg^{-1})) + two foliar sprays of Nano-DAP (2 ml L^{-1}) at 20–25 and 45–50 DAT resulted in higher yield responses, which improved crop growth and yield.

Choudhary (2022) further reported that during the rabi season at Jabalpur, the integrated application of 50% P through DAP + 100% NK + seed treatment with Nano-DAP (5 ml kg^{-1}) + two foliar sprays (4 ml L^{-1} at 30 DAG and one week before flowering) produced the highest growth and yield.

The effectiveness of Nano-fertilizers on rice yield was examined by Parve et al. (2023), who found that applying 50% RDF + 50% Nano N, P, K, and $ZnSO_4$ at 25 kg ha^{-1} increased grain yield by 10.1% compared with the control. Singh et al. (2021) also studied cryo-milled Nano-DAP on wheat (monocot) and tomato (dicot) and reported that enhanced orthophosphate bioavailability improved growth and yield with inputs 75% lower than conventional DAP.

In rice (*Oryza sativa* L.), applying Nano-fertilizers at 400× dilution with 75% NPK + urea increased milled grain weight by 11.3% compared with 100% NPK + urea. Rostaman et al. (2021) further reported that transplanted rice achieved the highest grain yield under treatments of 50% N + 0% Zn + 100% P & K + two foliar sprays of Nano-N, Nano-Zn, and Nano-Cu.

Abdel-Aziz et al. (2016), in a study at Agriculture Research Station, Mansoura, Egypt, tested Nano-chitosan NPK fertilizer on wheat and found improvements in growth parameters, yield, and maturity duration. Benzon et al. (2015) similarly reported that both conventional and Nano-fertilizers enhanced rice yield attributes, including chlorophyll content, reproductive tillers, panicle characteristics, grain weight (unpolished +17.5%, polished +20.7%), shoot dry weight, and harvest index.

Kumar et al. (2014) demonstrated that wheat treated with Nano-gypsum and Nano-rock phosphate at 3 kg ha^{-1} showed yield parameters statistically superior to 100% RDF without Nano materials.

Collectively, these studies indicate that Nano-DAP, whether applied as a seed treatment, soil amendment, or foliar spray, significantly improves crop growth, yield attributes, and overall productivity. Moreover, integrating Nano-DAP with conventional fertilizer regimes allows for reduced chemical input while sustaining or even enhancing crop performance.

3.2. Nano-DAP effect on the nutrient status of soil

At Junagadh Agricultural University, Gujarat, Dhansil et al. (2018) reported that the application of Nano-phosphatic fertilizers improved soil N and P status compared with conventional fertilizers, allowing up to 40% replacement of chemical inputs. Rajonee et al. (2017) further showed that phosphorus Nano-fertilizer significantly increased soil-available P (30 ppm) compared with traditional fertilizer (14 ppm) and control (11 ppm) following the harvest of *Ipomoea aquatica* (kalmi).

Table 3. Research studies on Nano fertilizers regarding the nutrient status of soil

Author(s)	Location & Crop	Treatment Details	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Key findings
Kushwaha et al. (2024)	Okra field	T9: 100% Nano Urea @ 1.23 L ha^{-1} + 100% Nano DAP @ 1.23 L ha^{-1} + K RD @ 83.3 kg ha^{-1}	284.16	34.63	256.03	Best result for all NPK availability among treatments.
Parmar et al. (2024)	Anand Agricultural University, Wheat	T2: 100% RDF of N and P	211	55	–	Higher N and P availability under full RDF with Nano DAP.
Chamuah et al. (2023)	Assam Agricultural University, Cabbage	T9: 130:0:80 kg NPK ha^{-1} + ST of n-DAP @ 5 ml L^{-1} + FS of n-DAP @ 6 ml L^{-1} at 25–30 DAT	291.03	–	–	The maximum available N observed under this treatment.
		T13: 50% P, 50% N & 100% K + ST @ 5 ml L^{-1} + FS of n-DAP @ 2 ml L^{-1} at 25–30 DAT	–	20.88	–	Higher P availability noted under partial substitution with Nano DAP.
		T4: 100% N & K (130:80 kg ha^{-1}) + Seedling root treatment of n-DAP @ 5 ml L^{-1}	–	–	95.04	K availability was highest in this treatment among cabbage treatments.

In Egypt, Hasaneen et al. (2016) evaluated French bean grown in clay sandy soil using carbon nanotube-coated P and chitosan nanoparticle-P fertilizers. They observed that Nano-fertilizer application enhanced post-harvest soil nutrient availability, with higher doses further increasing nutrient concentrations in the soil solution. However, this also elevated soil osmotic potential, which slightly reduced plant uptake. Similarly, Rajonee et al. (2017) confirmed that Nano-N fertilizer treatments significantly increased soil N content after *Ipomoea aquatica* harvest compared with conventional treatments.

Prakash et al. (2023) at ICAR-KVK, Kalaburagi, found that T7 treatment (100% RDF + foliar spray of Nano-DAP @ 4 ml L^{-1} at 30 and 45 DAS) resulted in significantly higher post-harvest nutrient availability after soybean, including 215 kg ha^{-1} N, 33.77 kg ha^{-1} P_2O_5, 351 kg ha^{-1} K_2O, and 17.28 kg ha^{-1} SO_4^{2-}. Rameshaiah et al. (2015) concluded that Nano-fertilizers can improve nutrient-use efficiency (NUE) by up to three times compared with chemical fertilizers, while also enhancing stress tolerance and reducing input costs.

From the reviewed literature, it is evident that Nano-DAP positively influences soil nutrient dynamics by enhancing nutrient availability, improving NUE, and contributing to balanced soil fertility. Its nanoscale size facilitates better penetration and absorption, reduces nutrient losses, and synchronizes nutrient release with plant demand. These findings collectively suggest that Nano-DAP supports sustainable nutrient management and holds promise for improving long-term soil health, as mentioned in Table 3..

3.3. Effect of Nano-DAP on nutrient use efficiency

An experiment on chickpea at the Pulse Research Unit, Dr. PDKV, Akola, conducted by Pandao et al. (2024), demonstrated that Nano-DAP enhanced nutrient uptake and improved nutrient-use efficiency. However, conventional 100% RDF consistently achieved higher agronomic efficiencies for nitrogen (35.04–35.76 kg ha^{-1}) and phosphorus (17.52–17.88 kg ha^{-1}) compared with Nano-DAP treatments.

At Anand Agricultural University, Parmar et al. (2024) studied wheat during the rabi season and found that significantly higher phosphorus uptake by grain (25.01 kg ha^{-1}) was recorded with T2 (100% RDF N and P), which was statistically at par with other treatments.

Overall, the literature indicates that the ultra-small particle size of Nano-DAP reduces nutrient losses commonly observed in granular fertilizers, thereby improving nutrient-use efficiency and contributing to more sustainable fertilization practices. A summary of research findings on nutrient-use efficiency is provided in Table 4.

3.4. Nano-DAP and economic viability

At the research farm of Dr. C.V. Raman University, Khandwa (Madhya Pradesh), Tomar et al. (2024) evaluated Nano-DAP on wheat (*Triticum aestivum*) during the rabi season. The highest benefit–cost (B: C) ratio of 2.52 was obtained with T5 (50% N and P + 100% K + seed treatment with Nano-DAP @ 5 ml kg^{-1} + foliar spray with Nano-DAP @ 4 ml L^{-1}), while the lowest B: C ratio of 1.46 was recorded in the control (T7).

Similarly, Chinnappa et al. (2023) at the Agricultural Research Station, Hagari, UAS Raichur (Karnataka), studied sorghum during the kharif season. The lowest B: C ratio (2.15) occurred under absolute control (T10), whereas T7 (75% recommended NP as basal + Nano-urea and Nano-DAP sprays @ 1.5 ml L^{-1} each at 30 and 45 DAS) achieved the highest B: C ratio of 2.90. A comparison of these findings is presented in Table 5.

Table 4. Nano fertilizer (nano DAP, nano urea, etc.) effect over nutrient use efficiency

Author(s)	Location & Crop	Treatment Details	Agronomic/Nutrient Use Efficiency	Key Findings
Chinnappa et al. (2023)	Agricultural Research Station, Hagari (Sorghum, Kharif season)	75% RNP as basal + Nano Urea & Nano DAP @ 1.5 ml L^{-1} each sprayed at 30 and 45 DAS	N: 17.5 kg seed kg^{-1} NP: 26.4 kg seed kg^{-1} P	Significantly higher agronomic efficiency for N and P compared to conventional treatments.
Chinnappa et al. (2023)	(Cotton crop, location not specified)	N50 P50 K100 + Nano DAP (Seed treatment @ 5 ml kg^{-1} seed + Foliar spray @ 0.2% at 30 DAS)	Phosphorus Use Efficiency: 22.96%	The highest phosphorus use efficiency was achieved under this treatment.
Singh et al. (2023)	SVP University of Agriculture & Technology, Western Uttar Pradesh (Wheat)	75% NPK + Nano N + Bio Nano P, K, Zn	N: 22.4P: 56.0 (Compared to 100% NPK: N: 9.4, P: 23.5)	The nano nutrient combination led to much higher nutrient use efficiency than full-dose conventional NPK.

Table 5. Economically viable treatments involving Nano DAP application across different crops

Author(s)	Location & Crop	Treatment Details	B:C Ratio (Highest)	Key Findings
Attri et al. (2023)	REC, Gaja (Finger Millet, Kharif)	T10: 50% P + 100% N + 100% K + ST + FS (4 ml) + FS (4 ml)	4.94	T10 gave the highest gross return and B: C ratio; T5 the lowest.
Attri et al. (2023)	SKUAST-Jammu (Kharif, unspecified crop)	T6: 75% N, 75% P, 100% K + Nano DAP @ 5 ml L^{-1} (seedling dip) + FS @ 4 ml L^{-1}	2.16	T6 recorded the maximum net return and profit coefficient.
Jagadeesh et al. (2024)	JNKVV, Jabalpur (Wheat, Rabi)	T10: 50% P + 100% N + 100% K + ST @ 5 ml kg^{-1} + FS @ 4 ml L^{-1} at 30 DAG and before flowering	2.96	T10 was the most profitable treatment in wheat.
Singh Rajput et al. (2022)	SGCA&RS, Jagdalpur (Little Millet, Kharif)	T12: 75% RDF + ST with nano fertilizer + FS at active tillering and 7–10 days before flowering	2.28	T12 showed the maximum B: C ratio; T2 showed the minimum.

Compared with conventional fertilizers, which require large quantities and increase input costs, Nano-DAP is applied in smaller amounts, thereby reducing the cost of cultivation. This enhanced economic efficiency makes Nano-DAP a more profitable and sustainable option for farmers.

3.5. Positives of using Nano-DAP

Numerous studies have documented the positive effects of Nano-fertilizers on plant growth and productivity. Plants treated with Nano-fertilizers generally exhibit significantly greater shoot and root length compared with those treated with conventional fertilizers. Crops receiving Nano-DAP tend to produce larger, well-developed fruits with favorable texture, color, and overall appearance, owing to a more balanced and efficient nutrient supply (Haydar et al., 2024).

Nano-DAP also improves the nutritional quality of crops by increasing the accumulation of essential nutrients such as vitamins, minerals, and proteins. In addition, it enhances phytochemical composition, leading to elevated levels of antioxidants and other bioactive compounds beneficial to human health (Rahale et al., 2025).

Another advantage is its role in stress tolerance. Plants grown with Nano-DAP demonstrate greater resilience to environmental stresses, particularly drought. This is attributed to stronger root systems that enhance nutrient and water uptake and support better water retention in plant tissues (Razauddin et al., 2023).

3.6. Limitations of Nano-DAP

Despite these benefits, current knowledge of Nano-DAP remains limited. In many cases, experimental data are presented without detailed mechanistic explanations of how Nano-DAP functions at the plant–soil–microbe interface. This knowledge gap restricts the ability to fine-tune applications and predict long-term outcomes.

Most existing studies are short-term, typically spanning only a few crop cycles, with limited assessment of long-term impacts. Unresolved issues include nanoparticle persistence in soil, formulation stability over time, and interactions with soil microbial communities (Gupta et al., 2024).

Potential ecological and health risks also remain a concern. Nanoparticle bioaccumulation and possible human health effects require cautious evaluation before widespread adoption (Pandey et al., 2025). Furthermore, the majority of studies have been carried out under greenhouse or controlled conditions, which may not fully reflect the complexity of open-field environments, raising questions about scalability and general applicability.

Finally, regulatory frameworks for Nano-DAP are still under development. The absence of standardized guidelines and policies underscores the urgent need for robust regulations to ensure safe, responsible, and effective use (Razauddin et al., 2023).

4. Future Perspectives

Nano-DAP represents a promising innovation for building resource-efficient and climate-resilient agricultural systems. It offers significant potential for reducing farmers' input costs while enhancing crop productivity (Basavegowda & Baek, 2021). One of its major strengths lies in improving phosphorus delivery. Unlike conventional DAP, which is pH dependent and prone to fixation in the soil, Nano-DAP improves phosphorus solubility and availability, ensuring more efficient uptake by plants.

Moreover, Nano-DAP provides a controlled and gradual nutrient release that matches plant growth stages. This slow-release mechanism enhances nutrient-use efficiency, reduces leaching losses, and minimizes environmental contamination (Demeke et al., 2025). Importantly, Nano-DAP does not significantly alter soil pH, thereby preserving soil health and sustaining microbial activity. Improved nutrient accessibility translates into higher yields, better seed quality, and greater resilience to abiotic stress compared with untreated plants.

However, several challenges must be addressed before Nano-DAP can achieve widespread adoption. Key barriers include insufficient long-term studies on environmental and health impacts, relatively higher production costs compared with conventional fertilizers, limited market availability, and the need for technical knowledge to ensure proper application. These factors increase the risk of misuse, potential toxicity, and disruption of soil microbial balance. In addition, the absence of standardized regulations and quality control mechanisms raises further concerns.

By contrast, conventional fertilizers remain dominant in agriculture due to their affordability, availability, and well-established guidelines. They provide rapid responses in nutrient-deficient soils and are backed by decades of field-based research, making them the more familiar and accessible choice for most farmers.

Nevertheless, Nano-DAP aligns with global sustainability goals by reducing fertilizer consumption and minimizing environmental impacts. Future efforts should focus on optimizing formulations, tailoring application strategies for diverse soils and cropping systems, and conducting multi-season field trials under real-world conditions. Developing robust regulatory frameworks, improving cost-effectiveness, and enhancing farmer training will be crucial for ensuring the safe and effective integration of Nano-DAP into sustainable agricultural practices.

5. Conclusion

This review underscores the significant potential of Nano-diammonium phosphate (Nano-DAP) to improve nutrient management in modern agriculture. Compared with conventional fertilizers, Nano-DAP offers more efficient phosphorus release, enhanced nutrient uptake, and measurable improvements in crop growth and yield. However, the widespread adoption of this technology requires a stronger evidence base. Long-term, field-based studies are particularly needed to assess its agronomic performance, environmental safety, and economic feasibility under diverse farming conditions.

As global agriculture strives to address the dual challenges of food security and sustainability, Nano-DAP and other Nano-fertilizers may serve as key tools in developing resource-efficient production systems. Realizing this potential will depend on clear regulatory frameworks, standardized guidelines, and effective farmer training to ensure safe and responsible use. With continued research and supportive policies, Nano-DAP can contribute to higher productivity, improved nutrient-use efficiency, and reduced environmental impacts, thereby advancing the goal of resilient and sustainable farming systems.

Declaration of Competing Interest

The authors declare that no competing financial or personal interests may appear to influence the work reported in this paper.

References

Abdel-Aziz, H. M., Hasaneen, M. N., & Omer, A. M. (2016). Nano chitosan-NPK fertilizer enhances the growth and productivity of wheat plants grown in sandy soil. *Spanish Journal of Agricultural Research*, *14*(1), e0902-e0902. https://doi.org/10.5424/sjar/2016141-8205.

Attri, M., Sharma, N., Mehta, S., & Mecarty, J. S. (2023). Effects of seedling dipping and foliar application of nano dap on growth, yield and economics of fine rice. *Bangladesh Journal of Botany*, *52*(4), 1025-1031. https://doi.org/10.3329/bjb.v52i4.70589.

Babu, U., Shukla, A. K., Kumar, A., & Meena, R. K. (2021). Effect of sowing methods and nutrients on growth and yield of wheat *(Triticum aestivum* L.): a review. *Current Research in Agriculture and Farming*, *2*(2), 18-22. https://doi.org/10.18782/2582-7146.135.

Basavegowda, N., & Baek, K.-H. (2021). Current and future perspectives on the use of nanofertilizers for sustainable agriculture: the case of phosphorus nanofertilizer. *3 Biotech*, *11*(7), 357. https://doi.org/10.1007/s13205-021-02907-4.

Benzon, H. R. L., Rubenecia, M. R. U., Ultra, J. V. U., & Lee, S. C. (2015). Chemical and biological properties of paddy soil treated with herbicides and pyroligneous acid. *Journal of agricultural science*, *7*(4), 20. https://doi.org/10.5539/jas.v7n4p20.

Chamuah, S., Gogoi, S., Dutta, S., Bhattacharjee, D., Sharma, S., & Das, K. (2023). Impact of Nano-Dap on Growth and Development of Cabbage. *International Journal of Environment and Climate Change*, *13*(12), 1298–1304. https://doi.org/10.9734/ijecc/2023/v13i123795.

Chinnamuthu, C., & Boopathi, P. M. (2009). Nanotechnology and Agroecosystem. *Madras Agricultural Journal*, *96*, 17–31. https://doi.org/10.29321/MAJ.10.100436.

Chinnappa, S. A., Krishnamurthy, D., Ajayakumar, M. Y., Ramesha, Y. M., & Ravi, S. (2023). Effect of Nano Fertilizers on Growth, Yield, Nutrient Uptake and Soil

Microbiology of Kharif Sorghum. *International Journal of Environment and Climate Change*, *13*(10), 2339–2348. https://doi.org/10.9734/ijecc/2023/v13i102899.

Choudhary, S. (2022). *Effect of Nano DAP on Growth and Yield of Wheat* [Master thesis, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, India].

Demeke, E. D., Benti, N. E., Terefe, M. G., Anbessa, T. T., Mengistu, W. M., & Mekonnen, Y. S. (2025). A comprehensive review on nano-fertilizers: preparation, development, utilization, and prospects for sustainable agriculture in Ethiopia [10.1039/D4NA01068J]. *Nanoscale Advances*, *7*(8), 2131-2144. https://doi.org/10.1039/D4NA01068J.

Deo, H. R., Chandrakar, T., Srivastava, L., Nag, N., Singh, D., & Thakur, A. (2022). Effect of Nano-DAP on yield, nutrient uptake and nutrient use efficiency by rice under Bastar plateau. *Pharma Innovation Journal*, *11*(9), 1463-1465. https://www.thepharmajournal.com/archives/?year=2022&vol=11&issue=9&ArticleId=15550.

Dhansil, A., Zalawadia, N., Prajapat, B. S., & Yadav, K. (2018). Effect of nano phosphatic fertilizer on nutrient content and uptake by pearl millet (*Pennisetum glaucum* L.) crop. *International Journal of Current Microbiology and Applied Sciences*, *7*(12), 2327-2337. https://doi.org/10.20546/ijcmas.2018.712.264.

El-Ghany, M. F. A., El-Kherbawy, M. I., Abdel-Aal, Y. A., El-Dek, S. I., & Abd El-Baky, T. (2021). Comparative Study between Traditional and Nano Calcium Phosphate Fertilizers on Growth and Production of Snap Bean (*Phaseolus vulgaris* L.) Plants. *Nanomaterials*, *11*(11), 2913. https://doi.org/10.3390/nano11112913.

EPWRF India Time Series. (2023). *Agriculture: All India & State*. https://epwrfits.in/Agriculture_All_India_State.aspx

Gupta, S., Kumar, D., Aziz, A., A. E. AbdelRahman, M., Mustafa, A.-r. A., Scopa, A., . . . Moursy, A. R. (2024). Nanoecology: Exploring Engineered Nanoparticles' Impact on Soil Ecosystem Health and Biodiversity. *Egyptian Journal of Soil Science*, *64*(4), 1637-1655. https://doi.org/10.21608/ejss.2024.304704.1814.

Hasaneen, M. N. A., Abdel-Aziz, H. M. M., & Omer, A. M. (2016). Effect of Using Two Different Types of Engineered Nanomaterials on The Growth and Antioxidant Enzymes of French Bean Plants. *Journal of Plant Production*, *7*(9), 1021-1025. https://doi.org/10.21608/jpp.2016.46872.

Haydar, M. S., Ghosh, D., & Roy, S. (2024). Slow and controlled release nanofertilizers as an efficient tool for sustainable agriculture: Recent understanding and concerns. *Plant Nano Biology*, *7*, 100058. https://doi.org/10.1016/j.plana.2024.100058.

IFFCO. (2022). *Nano DAP: A novel nano fertilizer for sustainable agriculture*. Indian Farmers Fertiliser Cooperative Limited https://nanodap.in/en/nano-dap

Ijaz, S., Iqbal, J., Abbasi, B. A., Ullah, Z., Ijaz, N., Yaseen, T., . . . Mahmood, T. (2024). Regulatory and Ethical Concerns of Nanotechnology in Agriculture. In R. Shahzad, S. Fiaz, A. Qayyum, M. Ul Islam, & I.-J. Lee (Eds.), *Revolutionizing Agriculture: A Comprehensive Exploration of Agri-Nanotechnology* (pp. 395-427). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-76000-6_18

Jagadeesh, V., Deshmukh, M., & Pilewad, S. (2024). Studies on effect of NANO DAP on yield and nutrient uptake of soybean grown on Vertisol. *International Journal of Research in Agronomy*, *7*(10), 672-677. https://doi.org/10.33545/2618060X.2024.v7.i10i.1877.

Kekeli, M. A., Wang, Q., & Rui, Y. (2025). The Role of Nano-Fertilizers in Sustainable Agriculture: Boosting Crop Yields and Enhancing Quality. *Plants*, *14*(4), 554. https://doi.org/10.3390/plants14040554.

Khati, V., Kumar, A., Kishore, A., Paliwal, A., Raj, P., Rawat, A., . . . Kumar, P. (2024). Optimization of Nano-DAP Fertilization for Improvement in Growth and Yield of Finger Millet (*Eleusine coracana* (L.) Gaertn.). *Journal of Advances in Biology & Biotechnology*, *27*(11), 532–541. https://doi.org/10.9734/jabb/2024/v27i111637.

Kumar, K., & Dahiya, S. (2024). The comparative impact of chemical fertilizers, nano-urea and nano-DAP on growth and yield of wheat crop. *International Journal of Advanced Biochemistry Research*, *8*(7), 1133-1139. https://doi.org/10.33545/26174693.2024.v8.i7n.1714.

Kumar, N. V., Pallavi, K. N., Rajput, P., Bhargavi, B., Chandra, M. S., Chandana, P., . . . Rajput, V. D. (2025). Nano-Biochar: A promising tool for sustainable agriculture under climate change era. *Sains Tanah Journal of Soil Science and Agroclimatology*, *22*(1), 18. https://doi.org/10.20961/stjssa.v22i1.100809.

Kumar, R., Pandey, D. S., Singh, V. P., & Singh, I. P. (2014). *Nanotechnology for Better Fertilizer Use (Research Experiences at Pantnagar). Research Bulletin No: 201*. Directorate of Experiment Station, G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India. https://doi.org/10.13140/2.1.1406.6244

Kushwaha, R. K., Bharose, R., Tripathi, M., Katiyar, D., Singh, R. K., Rajput, R., & Kapat, T. (2024). Effect of nano urea and nano dap conjugated with potassium on physical and chemical properties of soil, growth and yield of okra crop (*Abelmoschus esculentus* L.) var Sudha. *International Journal of Advanced Biochemistry Research*, *8*(7), 633-637. https://doi.org/10.33545/26174693.2024.v8.i7h.1560.

Meena, D., Bijarnia, A. L., Sharma, R. L., & Gharsiram. (2024). Yield Performance of Chickpea under Foliar Application of Nano Urea and Nano Zn Fertilizers under the arid Condition of Western Rajasthan *Biological Forum – An International Journal*, *16*(7), 1-5. https://www.researchtrend.net/bfij/pdf/1%20Yield-Performance-of-Chickpea-under-Foliar-Application-of-Nano-Urea-and-Nano-Zn-Fertilizers-under-the-arid-Condition-of-Western-Rajasthan-Dharmendra-Meena-1.pdf.

Mim, J. J., Rahman, S. M. M., Khan, F., Paul, D., Sikder, S., Das, H. P., . . . Hossain, N. (2025). Towards smart agriculture through nano-fertilizer-A review. *Materials Today Sustainability*, *30*, 101100. https://doi.org/10.1016/j.mtsust.2025.101100.

Muktamar, Z., Lifia, L., & Adiprasetyo, T. (2020). Phosphorus availability as affected by the application of organic amendments in Ultisols. *Sains Tanah Journal of Soil Science and Agroclimatology*, *17*(1), 7. https://doi.org/10.20961/stjssa.v17i1.41284.

Pandao, M. R., Deshmukh, P., Bhoyar, S., & Sajid, M. (2024). Enhancing chickpea yield and nutrient efficiency in vertisols using nano diammonium phosphate. *International Journal of Advanced Biochemistry Research*, *8*(8), 1224-1227. https://doi.org/10.33545/26174693.2024.v8.i8p.1975.

Pandey, K. P., Kalhapure, A., Mishra, S., Chaubey, A., Kumar, A., Gautam, B., & Kumar, S. (2025). Influence of Nano Urea and Nano DAP on Crop Nutrient Content, Uptake and Soil Fertility Status in Blackgram (*Vigna mungo*). *Plant Archives*, *25*(1), 2799-2806. https://www.plantarchives.org/article/405-%20Influence%20of%20Nano%20Urea%20and%20Nano%20DAP%20on%20Crop%20Nutrient%20Content,%20Uptake%20and%20Soil%20Fertility%20Status%20in%20Blackgram%20(Vigna%20mungo).pdf.

Parmar, G. S., Viradiya, M. B., & Patel, J. A. (2024). Response of Nano Dap on Yield and Nutrient Content of Wheat Grown in Loamy Sand Soil. *International Journal of Plant & Soil Science*, *36*(8), 374–383. https://doi.org/10.9734/ijpss/2024/v36i84866.

Parve, M., Mane, M., Bodake, P., Rajemahadik, V., Dhopawkar, R., Mane, A., . . . Thorat, A. (2023). Effect of foliar application of nano-urea on nutrient quality and yield of kharif rice (*Oryza sativa* L.) under lateritic soil condition. *The Pharma Innovation Journal*, *12*(12), 1366-1370. https://www.thepharmajournal.com/archives/2023/vol12issue12/PartP/12-12-78-661.pdf.

Poudel, A., Singh, S. K., Jiménez-Ballesta, R., Jatav, S. S., Patra, A., & Pandey, A. (2023). Effect of Nano-Phosphorus Formulation on Growth, Yield and Nutritional Quality of Wheat under Semi-Arid Climate. *Agronomy*, *13*(3), 768. https://doi.org/10.3390/agronomy13030768.

Prakash, Naik, A., Siddaram, Ravi MV, & Bellakki MA. (2023). Effect of Nano DAP on Nutrient uptake and Available Nutrients Status of Soil after Harvest of Soybean (*Glycine max* L.). . *The Pharma Innovation Journal*, *12*(12), 1990-1994. https://www.thepharmajournal.com/archives/?year=2023&vol=12&issue=12&ArticleId=24833.

Rahale, S., Subramanian, K., Kalarani, M., Umapathy, M., Mohanraj, J., Parida, B., & Srinivasan, G. (2025). Foliar Feeding of Gromor Nano DAP on Physiological, Biochemical and Nutritional Changes in Rice. *PREPRINT (Version 1) available at Research Square*. https://doi.org/10.21203/rs.3.rs-6238153/v1.

Rajonee, A. A., Zaman, S., & Huq, S. M. I. (2017). Preparation, characterization and evaluation of efficacy of phosphorus and potassium incorporated nano fertilizer. *Advances in Nanoparticles*, *6*(02), 62-74. https://doi.org/10.4236/anp.2017.62006.

Rakshit, A., Singh, H. B., Singh, A. K., Singh, U. S., & Fraceto, L. (2020). *New frontiers in stress management for durable agriculture*. Springer. https://doi.org/10.1007/978-981-15-1322-0

Rameshaiah, G., Pallavi, J., & Shabnam, S. (2015). Nano fertilizers and nano sensors–an attempt for developing smart agriculture. *International Journal of Engineering Research and General Science*, *3*(1), 314-320. http://pnrsolution.org/Datacenter/Vol3/Issue1/40.pdf.

Razauddin, Ninama, J., Sachan, K., Sulochna, Yadav, B., Satapathy, S. N., . . . Singh, B. V. (2023). Effects and Consequences of Nano Fertilizer Application on Plant Growth and Developments: A Review. *International Journal of Environment and Climate Change*, *13*(10), 2288–2298. https://doi.org/10.9734/ijecc/2023/v13i102893.

Rostaman, T., Wibowo, H., & Nurjaya. (2021). The effects of nano inorganic fertilizer application on rice (*Oryza sativa* L) productivity. *IOP Conference Series: Earth and Environmental Science*, *648*(1), 012197. https://doi.org/10.1088/1755-1315/648/1/012197.

Shete, A., Adsul, P., Sabale, A., & Bobade JR. (2024). Impact of nano-DAP on growth & yield of black gram (*Vigna mungo* L.) in inceptisol soil. *International Journal of Research in Agronomy*, *7*(11), 47-52. https://doi.org/10.33545/2618060X.2024.v7.i11a.1921.

Singh, B. V., Rana, N. S., Kurdekar, A. K., Verma, A., Saini, Y., Sachan, D. S., . . . Tripathi, A. M. (2023). Effect of Nano and Non-Nano Nutrients on Content, Uptake and NUE of Wheat (*Triticum aestivum* L.). *International Journal of Environment and Climate Change*, *13*(7), 551–558. https://doi.org/10.9734/ijecc/2023/v13i71907.

Singh, N. R. R., Sarma, S. S., Rao, T. N., Pant, H., Srikanth, V. V. S. S., & Kumar, R. (2021). Cryo-milled nano-DAP for enhanced growth of monocot and dicot plants [10.1039/D1NA00283J]. *Nanoscale Advances*, *3*(16), 4834-4842. https://doi.org/10.1039/D1NA00283J.

Singh Rajput, J., Thakur, A., Nag, N., Chandrakar, T., & Singh, D. (2022). Effect of nano fertilizer in relation to growth, yield and economics of little millet (*Panicum sumatrense* Roth) under rainfed conditions. *Pharma Innovation Journal*, *11*(7), 153-156. https://www.thepharmajournal.com/archives/?year=2022&vol=11&issue=7&ArticleId=14768.

Soni, S. K., Dogra, S., Sharma, A., Thakur, B., Yadav, J., Kapil, A., & Soni, R. (2024). Nanotechnology in Agriculture: Enhancing Crop Productivity with Sustainable Nano-Fertilizers and Nano-Biofertilizers. *Journal of Soil Science and Plant Nutrition*, *24*(4), 6526-6559. https://doi.org/10.1007/s42729-024-01988-3.

Tarafdar, J. C., Raliya, R., Mahawar, H., & Rathore, I. (2014). Development of Zinc Nanofertilizer to Enhance Crop

Production in Pearl Millet (*Pennisetum americanum*). *Agricultural Research*, *3*(3), 257-262. https://doi.org/10.1007/s40003-014-0113-y.

Tomar, M., Malgaya, G., Dubey, S., Singh, A., & Jalsingod, J. (2024). Effect of Nano DAP on Growth and Yield Performance of *Triticum aestivum* (L.) East Nimar Region, Khandwa, Madhya Pradesh, India. *International Journal of Plant & Soil Science*, *36*(8), 682–692. https://doi.org/10.9734/ijpss/2024/v36i84898.