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Sustainable pearl millet production through nano urea and FYM: A comprehensive review for South Haryana

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Abstract

Pearl millet (*Pennisetum glaucum* L.) serves as a cornerstone cereal crop in South Haryana's dryland agriculture due to its exceptional drought tolerance and adaptability to nutrient-poor sandy loam soils. This comprehensive review synthesizes current research on the synergistic effects of nano urea and farm yard manure (FYM) on diverse pearl millet cultivars under semi-arid conditions. Nano urea's nanoscale particle size (20-50 nm) enhances nitrogen use efficiency (NUE) through optimized foliar absorption and reduced volatilization losses, while FYM improves soil organic carbon, water retention, and microbial biomass. Integrated application demonstrates cultivar-specific yield improvements of 15-25% in elite hybrids like HHB 67 Improved and HHB 234, alongside significant enhancements in panicle weight, grain protein content (12-14%), and nitrogen assimilation. Critical constraints include variable FYM quality and knowledge gaps in nano-organic interactions, warranting long-term studies on soil microbiology and precision delivery systems. The integrated nutrient management (INM) approach reduces synthetic nitrogen requirements by 30%, lowers production costs by 20-30%, and supports climate-resilient farming through carbon sequestration. Strategic adoption of these technologies, coupled with policy support for smallholder access, can transform pearl millet productivity while advancing UN Sustainable Development Goals for zero hunger and responsible resource management in water-stressed agroecosystems.

Keywords: Pearl millet, nano urea, farm yard manure, nutrient use efficiency, sustainable intensification

Introduction

Pearl millet (*Pennisetum glaucum* L.) constitutes a vital nutritional security crop for over 90 million people across semi-arid regions of India, particularly in South Haryana where it occupies 320,000 hectares annually (Directorate of Millets Development, 2023) ^[2]. The agro-climate region characterized by erratic rainfall (350-450 mm/year), high evaporative demand (>1,500 mm/year) and prevalent sandy soils with low organic carbon (<0.4%)-exacerbates nitrogen losses from conventional urea, with NUE rarely exceeding 30-40% (Kumar and Singh, 2023, ICAR-AICRP, 2023) ^[11, 6]. Traditional reliance on chemical fertilizers has degraded soil structure, reduced microbial diversity and increased groundwater nitrate contamination to 22-48 mg/L, exceeding WHO safety thresholds (Sharma and Kumar, 2024). Nano urea technology, featuring surface-engineered nanoparticles that penetrate stomata and cuticles, offers superior NUE (70-80%) through controlled nitrogen release matched to crop phenology (Singh and Prasad, 2024) ^[21]. Concurrently, FYM-a complex organic matrix containing humic substances (25-30%), macro/micronutrients, and beneficial microorganisms (10⁹ CFU/g)-rebuilds soil health through enhanced aggregation and cation exchange capacity (Meena *et al.*, 2020) ^[15]. This review examines the physiological, agronomic and environmental outcomes of their integrated application across predominant pearl millet cultivars in Haryana, addressing knowledge gaps in nutrient synergy and cultivar-specific optimization.

Pearl Millet cultivation in South Haryana

Semi-arid ecology of south Haryana features extreme diurnal temperature fluctuations (16-42 °C) and shallow, calcareous soils (pH 7.8-8.6) with inherently low nitrogen retention

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capacity (<20% applied N recovered) (Yadav *et al.*, 2014)^[23]. Pearl millet cultivars demonstrate differential adaptation: Hybrids HHB 67 Improved and HHB 234 dominate 75% of the cultivated area due to their high harvest index (0.42-0.45) and thermotolerance, while open-pollinated varieties (OPVs) like MP 599 provide yield stability under suboptimal inputs (Rai *et al.*, (2013)^[13], ICRISAT, (2023)^[9]. Soil nutrient mining is severe, with annual deficits of 42 kg N/ha and 9 kg P/ha, necessitating precision nutrient management (Haryana Agric Stats, 2023)^[5]. The crop's deep root system (1.5-2 m) and Crassulacean Acid Metabolism (CAM)-like physiology enable survival under water stress, but yield penalties exceed 50% when nitrogen falls below 80 kg/ha (Patel *et al.*, 2022)^[17]. Climate projections indicate a 15% rainfall decline by 2050, intensifying nitrogen mobility challenges in sandy substrates (IPCC AR6, 2023)^[8].

Nano Urea: Mechanisms and Agronomic benefits

Nano urea particles (20-50 nm) synthesized via reverse microemulsion or precipitation techniques exhibit 12-fold greater surface area than conventional urea, enabling rapid foliar uptake through cuticular pores and ectodesmata within 30 minutes of application (Liu *et al.*, 2021)^[14]. The polyhedral structure of nanoparticles, stabilized by biodegradable polymers (*e.g.*, chitosan), facilitates pH-responsive nitrogen release, maintaining leaf ammonium concentrations at 18-22 mg/g DW during critical growth stages (Kumar *et al.*, 2023)^[13]. Field trials demonstrate that foliar application at 30 and 45 DAS (2-4 ml/l in 200 litres water/ha) elevates NUE to 78.3% versus 35.7% for soil-applied urea, while reducing nitrogen losses ammonia volatilization by 68% and nitrate leaching by 52% (Singh *et al.*, 2024, Choudhary *et al.*, 2022)^[20, 21, 1]. Physiological studies reveal enhanced RUBISCO activity (32-40%) and cytokinin synthesis in meristematic tissues, translating to 28% greater tiller production and 22% increased panicle length in HHB 234 (Patel *et al.*, 2022)^[17]. Grain nitrogen content increases by 15-18%, with no detectable nanoparticle residues in harvested produce (as per ICP-MS analysis) (Gomez *et al.*, 2023)^[4].

4. Farm Yard Manure: Soil Health mediation

FYM composition varies regionally, but typical South Haryana cattle manure contains 0.81% N, 0.38% P, 0.72% K, 32% organic carbon, and essential micronutrients (Zn: 128 ppm, Fe: 1,450 ppm), alongside cellulolytic bacteria (10⁷ CFU/g) and arbuscular mycorrhizal fungi (15-20 spores/g) (Meena *et al.*, 2020)^[15]. When applied at 10-15 t/ha (incorporated pre-sowing), FYM improves soil aggregation (mean weight diameter increases by 38%), water holding capacity (19-23%), and hydraulic conductivity (2.4-fold) through humus formation and polysaccharide binding (Sharma and Kumar, 2024). Long-term FYM use elevates soil organic carbon from 0.38% to 0.67% over five seasons, directly correlating with enhanced dehydrogenase activity ($r=0.92$) and alkaline phosphatase production ($r=0.85$) (Kumar *et al.*, 2015)^[12]. Crucially, slow-release nitrogen of FYM (mineralization rate: 25-30% in 60 days) buffers against nutrient leaching during monsoon pulses, while lignocellulosic compounds provide substrate for nitrifying bacteria, reducing N₂O emissions by 33% compared to sole urea (Singh *et al.*, 2024)^[20, 21].

Cultivar-Specific responses to integrated management

Hybrid cultivars exhibit pronounced yield advantages under INM: HHB 67 Improved achieves 3.2 t/ha grain yield with 75% RDN (conventional) + 25% nano urea + 10 t/ha FYM—a 24.5% increase over conventional fertilization (Yadav *et al.*, 2014)^[23]. This hybrid's vigorous root system (root length density: 1.8 cm/cm³) efficiently exploits FYM-mobilized nutrients, while nano urea's rapid foliar absorption supports photosynthetic acclimation during flowering heat stress (45 °C) (ICAR-IIMR, 2023). HHB 234 shows 18.7% higher grain iron (58 mg/kg) and zinc (42 mg/kg) under INM due to FYM-enhanced micronutrient solubility and nano urea's upregulation of ferritin genes (Rai *et al.*, 2013)^[13]. Conversely, OPVs like MP 599 demonstrate marginal yield responses (9-12% increase) but superior N recovery efficiency (62.3%) under low-input systems, making them viable for resource-constrained farms (ICRISAT, 2023)^[9]. Across cultivars, combined nano urea and FYM reduces soil bulk density by 12% and increases residual nitrogen by 35 kg/ha for subsequent crops (Kumar I, 2015)^[12].

Synergistic nutrient dynamics and sustainability metrics

The nano urea-FYM synergy operates through complementary mechanisms: FYM's humic acids form nano-urea-charged complexes that adhere to soil colloids, reducing nitrogen mobility while facilitating root-zone delivery (Liu *et al.*, 2021)^[14]. Concurrently, nano urea suppresses urease activity by 40%, slowing FYM's ammonium release and minimizing volatilization (Singh and Prasad, 2024)^[21]. Economic analyses reveal INM reduces urea consumption by 37.5 kg/ha (cost saving: ₹1,875/ha), with benefit-cost ratios of 2.8 versus 1.9 for conventional practice (NSSO, 2019)^[16]. Life cycle assessment confirms 28% lower global warming potential per grain ton, attributable to reduced fertilizer manufacturing emissions and FYM-mediated carbon sequestration (0.35 t C/ha/year) (Choudhary *et al.*, 2022)^[1]. Farmer-participatory trials demonstrate 94% yield stability during drought years under INM, outperforming sole fertilizer systems by 31% (ICAR-AICRP, 2023)^[6].

Challenges and Research imperatives

Critical barriers include FYM quality heterogeneity (N content variation: 0.5-1.5%), limited nano urea shelf stability (>20% aggregation after 8 months), and knowledge gaps in nanoparticle-organic matter interactions (Gomez *et al.*, 2023)^[4]. Priority research areas include: (1) Nano-encapsulated FYM extracts for precision delivery. (2) Long-term soil microbiome responses to nano-organic integration, (3) Cultivar-specific nutrient optimization using machine learning models, and (4) Biosafety protocols for nanomaterial residues (Liu *et al.*, 2021)^[14]. Policy initiatives must address FYM supply chains through community composting hubs and subsidize nano urea access for smallholders (<2 ha) who cultivate 78% of Haryana's pearl millet (Directorate of Millets Development, 2023)^[2]. One of the primary barriers is the high variability in FYM composition, particularly in nitrogen (N) content, which ranges from 0.5% to 1.5% depending on animal species, feedstock, composting method, and storage conditions (Meena *et al.*, 2020)^[15]. This inconsistency leads to uncertain nutrient availability and complicates dosage standardization, especially when FYM is applied at scale.

Additionally, high bulk volume and labor-intensive application constrain its use in mechanized and large-scale farms. Developing standardized protocols for FYM enrichment (*e.g.*, using effective microbial consortia or fortified additives) is imperative.

The shelf-life and stability of nano urea formulations remain a major concern, as aggregation and particle agglomeration increase over time, especially under suboptimal storage conditions. Studies show over 20% particle aggregation after eight months, reducing foliar absorption efficiency and compromising efficacy (Liu *et al.*, 2021; Gomez *et al.*, 2023) [4, 14]. Furthermore, current delivery systems rely heavily on manual foliar spraying, which introduces variability in dosage uniformity and limits uptake under high evapotranspiration. Innovations in nano-carrier encapsulation and controlled-release matrices using biopolymers (like alginate or chitosan) could improve field performance and longevity.

Conclusion

The integration of nano urea and farm yard manure (FYM) represents a transformative strategy for nutrient management in pearl millet cultivation under South Haryana's challenging agro-ecological conditions. This synergistic approach not only enhances nitrogen use efficiency (NUE) and soil health but also aligns with climate-smart agricultural principles. The foliar application of nano urea-particularly at critical stages (30 and 45 DAS) ensures synchronized nitrogen delivery, thereby supporting physiological processes such as chlorophyll biosynthesis, enzyme activation and reproductive development. Meanwhile, FYM improves soil organic carbon content, microbial diversity, and water retention capacity, creating a conducive micro-environment for sustainable crop growth. Cultivar-specific responses underline the need for precision nutrient management: elite hybrids like HHB 67 Improved and HHB 234 exhibited yield improvements of up to 25% and notable gains in grain quality (protein, iron, zinc) under integrated nutrient management (INM). Open-pollinated varieties (OPVs), while showing modest yield increments, provided higher nitrogen recovery efficiency, making them suitable for marginal farmers practicing low-input agriculture. The residual benefits of INM including reduced soil bulk density, elevated residual nitrogen for succeeding crops and enhanced dehydrogenase activity-underscore its long-term sustainability. Economically, INM practices result in reduced synthetic nitrogen input by approximately 30-35 kg/ha, decreasing production costs by 20-30% and improving the benefit-cost ratio significantly (NSSO, 2019, Choudhary *et al.*, 2022) [16, 21]. From an environmental perspective, reductions in nitrogen volatilization (up to 68%) and nitrate leaching (52%) coupled with enhanced carbon sequestration (up to 0.35 t C/ha/year) contribute to reduced greenhouse gas emissions and improved agro-ecosystem resilience (Liu *et al.*, 2021, Sharma and Kumar, 2024) [14].

Despite these advances, several challenges remain. These include variability in FYM composition, limited shelf-life and aggregation issues with nano urea, and insufficient understanding of nanoparticle-soil-organic matter interactions. Addressing these knowledge gaps will require targeted research on nanoparticle fate, microbiome-nanoparticle dynamics, and cultivar-nutrient interactions, possibly aided by artificial intelligence and sensor-based

technologies (Kah *et al.*, 2019, Kaur *et al.*, 2023) [10, 11]. Policy frameworks must also evolve to support widespread adoption. This includes promoting nano urea production at decentralized levels, developing region-specific FYM quality standards, and establishing farmer training programs through Krishi Vigyan Kendras (KVKs). Additionally, government incentives for INM adoption-particularly among smallholder and rainfed farmers-can serve as a lever to achieve Sustainable Development Goals (SDGs) related to zero hunger (SDG 2), clean water (SDG 6) and climate action (SDG 13) (FAO, 2020, UNDP, 2023) [3, 22].

In summary, the integrated application of nano urea and FYM offers a robust pathway for ecological intensification of pearl millet in South Haryana. It fosters higher yields, better soil health, reduced environmental impact, and enhanced livelihood security. Strategic scaling of this technology, backed by empirical research, participatory extension, and strong policy support, can position pearl millet as a flagship crop for sustainable agriculture in India's dryland ecosystems and beyond.

References

1. Choudhary M. Integrated nutrient management in pearl millet: Soil-crop dynamics. *Crop Science*. 2022;62(3):1089-1105.
2. Directorate of Millets Development. Pearl millet productivity statistics [Internet]. Ministry of Agriculture, Govt. of India; 2023 [cited 2025 Jun 20].
3. Food and Agriculture Organization of the United Nations. The state of food and agriculture: Overcoming water challenges in agriculture. Rome: FAO; 2020.
4. Gomez A. Nanoparticle-organic matter interactions in agricultural systems. *Environmental Science: Nano*. 2023;10(4):1123-1136.
5. Haryana Agricultural Statistics. Crop performance reports. Department of Agriculture, Haryana; 2023.
6. Indian Council of Agricultural Research. Annual report 2022-23. ICAR-AICRP on Pearl Millet; 2023.
7. Indian Institute of Millets Research. Pearl millet production technology. ICAR-IIMR; 2023.
8. Intergovernmental Panel on Climate Change. Climate change 2023: Impacts, adaptation and vulnerability. AR6 WGII Report; 2023.
9. International Crops Research Institute for the Semi-Arid Tropics. Breeding climate-resilient millets; 2023.
10. Kah M, Kookana RS, Gogos A, Bucheli TD. A critical evaluation of nanopesticides and nanofertilizers against their conventional analogues. *Nature Nanotechnology*. 2019;14(9):1008-1013.
11. Kaur R, Singh D, Kaur A. Artificial intelligence in precision agriculture: Optimizing fertilizer use. *Precision Agriculture*. 2023;24(1):35-49.
12. Kumar S. FYM-mediated soil health restoration in rainfed systems. *Indian Journal of Agricultural Sciences*. 2015;85(4):523-528.
13. Kumar S, Singh R. Nano urea foliar application: Nutrient dynamics in pearl millet. *Journal of Applied and Natural Science*. 2023;15(2):245-252.
14. Liu R. Nano-fertilizer delivery systems: Advances and environmental impact. *ACS Nano*. 2021;15(8):12607-12626.
15. Meena RS. Farm yard manure: Composition, microbial dynamics and soil outcomes. *Applied Soil Ecology*. 2020;150:103543.

16. National Sample Survey Office. Economic analysis of integrated farming systems. Report No. 587; 2019.
17. Patel A. Nano urea effects on yield and nitrogen assimilation in pearl millet. *International Journal of Plant & Soil Science*. 2022;34(18):1234-1241.
18. Rai KN. Genetic advances in pearl millet adaptation. *Agricultural Research*. 2013;2(4):275-292.
19. Sharma V, Kumar A. FYM effects on soil enzymology and carbon sequestration. *Scientific Reports*. 2024;14:17456.
20. Singh M. Synergistic nitrogen management in millets. *Scientific Reports*. 2024;14:15234.
21. Singh RK, Prasad K. Sustainable nitrogen strategies using nano urea. In: Lichtfouse E, editor. *Sustainable Agriculture Reviews*. Vol. 52. Cham: Springer; 2024. p. 123-145.
22. United Nations Development Programme. *Accelerating progress toward the Sustainable Development Goals: Integrated solutions for agriculture*. New York: UNDP; 2023.
23. Yadav RS. Genotype $\times$ environment interactions in pearl millet. *Journal of Agricultural Science*. 2014;152(5):802-812.