International Journal of Plant & Soil Science

Volume 38, Issue 2, Page 142-149, 2026; Article no.IJPSS.152270
ISSN: 2320-7035

Synergistic Effect of Conventional and Nano Urea on Growth, Yield, and Economics of Barley (*Hordeum vulgare* L.) in the Chitrakoot Region

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i25972

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/152270

Original Research Article

Received: 22/11/2025
Accepted: 10/02/2026
Published: 13/02/2026

Abstract

A field experiment was conducted during the Rabi season of 2024-25 at Nanaji Deshmukh Parisar Agriculture Farm, Chitrakoot, Satna (M.P.) to evaluate the effect of integrated nitrogen management using conventional urea and nano urea on barley (var. 'Devlaxmi'). The experiment was laid out in a Randomized Block Design with nine treatments and three replications, combining three levels of conventional nitrogen (50 %, 75 %, and 100 % of the recommended 80 kg N ha^{-1}) with one, two, or three foliar sprays of nano urea (2 % conc.) at critical growth stages. The results demonstrated that treatment T_3 [100 % N + 3 nano urea sprays (Tillering + Jointing + Booting)] produced significantly superior growth (plant height: 85.20 cm, tillers: 7.2 at 90 DAS) and yield

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Cite as: *Prasad Pandey, Narvada, U.S. Mishra, Pawan Sirothia, and Govind. 2026. "Synergistic Effect of Conventional and Nano Urea on Growth, Yield, and Economics of Barley (Hordeum Vulgare L.) in the Chitrakoot Region". International Journal of Plant & Soil Science 38 (2):142-49. https://doi.org/10.9734/ijpss/2026/v38i25972.*

attributes (spikes: 6.9 plot^{-1}, grains spike^{-1}: 212.96, test weight: 44.26 g), culminating in the highest grain yield (50.17 q ha^{-1}). This treatment also registered the maximum net return (₹ 49,515 ha^{-1}) and benefit-cost ratio (2.14). The application of 75 % N with three nano urea sprays (T_6) resulted in a yield (47.31 q ha^{-1}) that was competitive, suggesting a potential for partial substitution of conventional urea. It is concluded that the foliar application of nano urea, particularly in three splits alongside the full recommended dose of conventional N, is a highly effective and economically viable strategy for enhancing barley productivity in the sandy loam soils of the Chitrakoot region.

Keywords: Barley, nano urea; foliar application; grain yield; economics.

1. Introduction

Barley (*Hordeum vulgare* L.) is a cornerstone of global agriculture, ranking as the world's fourth most important cereal crop after wheat, rice, and maize (Ullrich, 2011), and holds a significant position as the second most important rabi cereal in India. Believed to have originated in the fertile crescent of Abyssinia and Southeast Asia (Zohary et al*.,* 2012), its evolutionary history is deeply intertwined with human civilization. The crop's unparalleled resilience is its defining characteristic, allowing it to thrive in adverse climatic conditions where other cereals fail, including drought, salinity, and alkalinity (Chen et al*.,* 2022). This hardiness makes it a preferred choice for farmers in low-rainfall regions, as it requires less water and exhibits superior tolerance to abiotic stresses compared to other winter cereals. Beyond its agronomic robustness, barley's utility is multifaceted. Its nutritional profile is what truly sets it apart and is driving its resurgence as a functional food. It is notably superior to wheat in its mineral and fibre content (Geng et al*.,* 2022), and its most celebrated component is beta-glucan, a water-soluble fibre proven to be highly effective in lowering blood cholesterol levels (Idehen et al*.,* 2017).

In India, the production volume of barley has shown a promising upward trend, with estimates suggesting a rise to about 2.22 million tons in fiscal year 2024. However, the pursuit of higher productivity has often relied on the imbalanced and indiscriminate use of high-analysis chemical fertilizers, a practice that has developed myriad problems such as the decline of soil organic matter (SOC), deterioration in the quality of crop produce, an increase in salinity and sodicity, and a rise in soil pollutants (Bhattacharyya et al*.,* 2023). Moreover, the constant and sole use of inorganic fertilizers leads to micronutrient insufficiencies, creates an imbalance in the plant and soil nutrient system, increases susceptibility to pest attacks, causes environmental degeneration, and contributes to the overall decline of soil health (Savci, 2012). This underscores the critical need for sustainable nutrient management strategies that can maintain yield without compromising soil health.

Nitrogen (N) is the key element in achieving consistently high yields in cereals like barley, as it is a fundamental constituent of crucial cell components including nucleic acids, amino acids, enzymes, and photosynthetic pigments (Masclaux-Daubresse et al*.,* 2010). The rate of its uptake and partitioning within the plant is largely determined by the interplay between supply and demand during various critical stages of plant growth (Garnett et al*.,* 2009). Conventional urea is the most common source of nitrogen fertilizer used worldwide due to its high nitrogen content (46 %) and relatively low cost. However, its efficiency is notoriously low, often below 50 %, due to significant losses via ammonia volatilization, nitrate leaching, and denitrification (Cantarella et al*.,* 2018). These losses not only represent a substantial economic waste for farmers but also contribute to serious environmental issues such as groundwater contamination and greenhouse gas emissions (Reddy et al*.,* 2024).

In response to the inefficiencies of conventional urea, nano urea has emerged as a revolutionary, enhanced-efficiency fertilizer designed to overcome these limitations. Nano urea consists of nitrogen nanoparticles typically in the size range of 20 - 50 nm, which possess a very high surface area-to-volume ratio (Manikandan & Subramanian, 2016). This nano-formulation allows for a unique mode of action; the particles are small enough to be absorbed directly through the stomata of leaves or the cuticle, facilitating easier and more efficient uptake by the plant (Tarafdar et al*.,* 2014). This enhanced delivery mechanism ensures that a greater proportion of the applied nitrogen is utilized by the crop, thereby significantly improving Nitrogen Use Efficiency (NUE) and potentially reducing the conventional urea requirement by up to 50 % (Subramanian et al., 2015). By providing a more synchronized release of nitrogen that aligns with crop demand, nano urea minimizes nutrient losses to the environment, mitigating pollution and reducing the carbon footprint of agriculture and support policy objectives related to sustainable agriculture, climate-smart nutrient management, and reduction of chemical fertilizer dependency (Subramanian et al., 2015; Dimpka & Bindraban, 2018; Dimkpa et al., 2020). The application of nano urea as a foliar spray offers several distinct agronomic advantages. Foliar feeding allows for the rapid correction of nutrient deficiencies during critical growth stages, bypassing the complexities and immobilization issues associated with soil application (Lateef et al*.,* 2016). Studies have shown that foliar application of nano urea can lead to better vegetative growth, manifested in improved plant height, a higher number of effective tillers, and an increased leaf area index (LAI), which enhances photosynthetic efficiency (Yadav et al*.,* 2023).

However, the optimal strategy for integrating nano urea with different doses of soil-applied nitrogen in barley production systems, particularly in the specific agro-climatic conditions of the Chitrakoot region, remains to be fully elucidated. Therefore, the present investigation "To study about the effect of N and Nano urea on barley crop in Chitrakoot area." was planned to assess the different levels of foliar application of nitrogenous fertilizer on growth and yield attributes, evaluate the optimum dose of fertilizer, manage nitrogen in foliar application with respect to replacement of granular form, and work out the economics of different treatments.

2. Materials and Methods

2.1 Experimental Site and Climate

The experiment was carried out at Nanaji Deshmukh Parisar Agriculture farm, Mahatma Gandhi Chitrakoot Gramoday Vishwavidyalaya Chitrakoot, Satna (M.P.) which lies in the semi-arid and sub-tropical region of Madhya Pradesh between 25.148°North latitude and 80.855°East longitude. The altitude of town is about 190-210 meter above mean sea level. The soil was moist, well drained with uniform plane topography. The soil of the experimental field was alluvial in origin, sandy loam in texture and slightly alkaline in reaction having pH 7.31 (1:2.5 soil: water suspension method given by Jackson, 1973), low in organic carbon percentage in soil is 0.34 per cent (Walkley and Black's rapid titration method given by Walkley and Black, 1934), low in available nitrogen 96.5 kg ha^{-1} (Alkaline permanganate method given by Subbiah and Asija, 1956), medium in available phosphorus as sodium bicarbonate-extractable P was 18.34 kg ha^{-1} (Olsen's calorimetrically method, Olsen et al*.,* 1954), high in available potassium was 215.94 kg ha^{-1} (Flame photometer method given by Hanway and Heidel, 1952).

2.2 Experimental Design and Treatments

The experiment was laid out in a Randomized Block Design (RBD) with three replications. Nine treatment combinations were tested, involving three levels of conventional N (50 %, 75%, and 100 % of 80 kg ha^{-1}) and one, two, or three foliar sprays of nano urea (2 % concentration) at different growth stages (Table 1). A uniform dose of P_2O_5 and K_2O (40 kg ha^{-1} each) was applied basally to all plots. Barley variety 'Devlaxmi' was sown on 24th November 2024 at a seed rate of 100 kg ha^{-1}.

Table 1. Treatment details of the experiment

Treatment Symbol	Treatment Details
T_1	100% N + 1 nano urea spray (Tillering Stage)
T_2	100% N + 2 nano urea sprays (Tillering + Jointing)
T_3	100% N + 3 nano urea sprays (Tillering + Jointing + Booting)
T_4	75% N + 1 nano urea spray (Tillering Stage)
T_5	75% N + 2 nano urea sprays (Tillering + Jointing)
T_6	75% N + 3 nano urea sprays (Tillering + Jointing + Booting)
T_7	50% N + 1 nano urea spray (Tillering Stage)
T_8	50% N + 2 nano urea sprays (Tillering + Jointing)
T_9	50% N + 3 nano urea sprays (Tillering + Jointing + Booting)

2.3 Data Collection and Analysis

Observations on plant height and number of tillers were recorded at 30, 60, and 90 Days After Sowing (DAS). At harvest, yield attributes like number of spikes per plot, spike length, number of grains per spike, and test weight (1000-grain weight) were measured. Grain yield was recorded from the net plot and converted to q ha^{-1}. Economics was calculated based on prevailing input and output prices. The data were subjected to Analysis of Variance (ANOVA) as per Panse and Sukhatme (1967), and the treatment means were compared using Critical Difference (C.D.) at a 5% probability level.

3. Results and Discussion

3.1 Growth Parameters

The integrated application of N and nano urea significantly influenced all growth parameters. Treatment T_3 [100 % N + 3 nano urea sprays (Tillering + Jointing + Booting Stage)] consistently resulted in the maximum plant height (85.20 cm at 90 DAS) and number of tillers (7.2 at 90 DAS), followed by T_2 [100 % N + 2 nano urea sprays (Tillering + Jointing Stage)]. The lowest values were recorded in T_7 [50 % N + 1 nano urea spray (Tillering Stage)] (Table 2). Plant population was also highest in T_3 (57.48 m^{-2}). Conventional urea provides a baseline N supply, while foliar-applied nano urea ensures a rapid and efficient N supplementation during critical growth stages, bypassing soil immobilization and loss pathways (Subramanian et al*.,* 2015). The high surface area-to-volume ratio of nano particles facilitates quicker stomatal uptake and assimilation, promoting cell division and elongation (Tarafdar et al*.,* 2014). This explains the improved plant height and tillering in T_2 and T_3, a finding consistent with Hasan and Saad (2019) who reported the superiority of nano fertilizer in improving plant height and tiller number in wheat. The increase in tiller number under nano urea treatments highlights its role in promoting axillary bud development and reducing tiller mortality, as nitrogen availability during tillering dictates the potential number of productive tillers (Javaheri et al*.,* 2014).

Table 2. Effect of treatments on plant height and number of tillers of barley

Treatment	Plant Height (cm) at 90 DAS	Number of Tillers at 90 DAS
T_1	78.36	6.1
T_2	82.43	6.8
T_3	85.20	7.2
T_4	73.69	5.5
T_5	76.15	5.9
T_6	80.34	6.4
T_7	70.24	4.9
T_8	72.56	5.2
T_9	75.41	5.7
SEm ±	0.59	0.05
C.D. (P=0.05)	1.77	0.16

Table 3. Effect of treatments on yield attributes and grain yield of barley

Treatment	Spikes $plot^{-1}$	Spike Length (cm)	Grains $spike^{-1}$	Test Weight (g)	Grain Yield (q ha^{-1})
T_1	5.9	7.90	202.37	42.98	46.62
T_2	6.5	8.14	208.71	43.82	48.52
T_3	6.9	8.27	212.96	44.26	50.17
T_4	5.2	7.59	191.24	42.05	43.28
T_5	5.7	7.79	198.64	42.62	45.82
T_6	6.2	8.01	205.35	43.29	47.31
T_7	4.6	7.38	179.25	41.26	41.25
T_8	4.9	7.46	185.36	41.81	42.61
T_9	5.4	7.67	195.49	42.31	44.37
SEm ±	0.05	0.05	1.37	0.27	0.38
C.D. (P=0.05)	0.17	0.16	4.11	NS	1.14

Table 4. Economics of barley cultivation as influenced by different treatments

Treatment	Cost (₹/ha)	Gross Return (₹)	Net Return (₹)	B:C Ratio
T_1	42,300	86,247	43,947	2.04
T_2	42,800	89,762	46,962	2.10
T_3	43,300	92,815	49,515	2.14
T_4	41,300	80,068	38,768	1.94
T_5	41,800	84,767	42,967	2.03
T_6	42,300	87,524	45,224	2.07
T_7	40,300	76,313	36,013	1.89
T_8	40,800	78,829	38,029	1.93
T_9	41,300	82,085	40,785	1.99

3.2 Yield Attributes and Yield

A similar trend was observed for yield attributes. Treatment T_3 [100 % N + 3 nano urea sprays (Tillering + Jointing + Booting Stage)] recorded the highest number of spikes per plot (6.9), spike length (8.27 cm), grains per spike (212.96), and test weight (44.26 g) (Table 3). Consequently, T_3 also produced the significantly highest grain yield of 50.17 q ha^{-1}, which was 21.6 % higher than the lowest yielding treatment T_7 [50 % N + 1 nano urea spray (Tillering Stage)] (41.25 q ha^{-1}). The synergistic effect was most pronounced in yield attributes. Nitrogen is crucial for floret development and grain filling. The timely availability of N from multiple nano urea sprays during tillering, jointing, and booting stages likely reduced floret abortion, increased the number of fertile spikelets, and enhanced the photosynthate translocation to the developing grains, resulting in more grains per spike and higher test weight (Yadav et al*.,* 2023). The nitrogen application led to an increase in leaf nitrogen concentration, which in turn improved plant's photosynthetic efficiency and enhanced nutrient uptake (Kumar et al*.* 2024). This directly translated into the highest grain yield in T_3. These results are in agreement with Pal et al*.* (2023) who found that the combination of 100 % nitrogen along with a foliar spray of nano urea had a significant positive impact on yield and yield parameters of wheat. Similarly, Singh et al*.* (2024) reported that barley fertilized with 100 % RDN + foliar spray of nano-nitrogen fertilizer produced maximum growth and grain yield. The competitive performance of T_6 [75 % N + 3 nano urea sprays (Tillering + Jointing + Booting Stage)], which yielded 47.31 q ha^{-1}, suggests a potential for saving 25% of conventional N without significant yield sacrifice, a finding supported by Rathour et al*.* (2024) and Meena et al*.* (2024) who reported that 75 % RDN with nano urea sprays could produce statistically similar yields to 100 % RDN in maize and pearl millet, respectively.

3.3 Economics

Economically, Treatment T_3 [100 % N + 3 nano urea sprays (Tillering + Jointing + Booting Stage)], despite having the highest cost of cultivation (₹ 43,300 ha^{-1}), generated the maximum gross return (₹ 92,815 ha^{-1}) and net return (₹ 49,515 ha^{-1}), resulting in the most favorable B:C ratio of 2.14 (Table 4). The lowest net return and B:C ratio were observed in T_7 [50 % N + 1 nano urea spray (Tillering Stage)]. The higher yield in T_3 comfortably offset its increased input cost, yielding the highest net returns and B:C ratio. The results align with findings of Kumar et al*.* (2023) and Singh et al*.* (2024), who reported that nano urea supplementation improves profitability in wheat and barley. Kannoj et al*.* (2022) also reported that the application of 50 % conventional urea + 50% nano urea fertilizer resulted in the utmost net return and benefit-cost ratio in black wheat. The economic benefits derive from two primary factors: increased yield output and reduced nitrogen wastage. Nano urea's high efficiency allows for a more precise delivery of nitrogen, reducing the need for excessive conventional urea applications without compromising yield (Subramanian et al*.,* 2015).

4. Conclusion

The study conclusively demonstrates that the integration of conventional urea with foliar sprays of nano urea significantly enhances the growth, yield, and profitability of barley. Among all treatments, T_3 [100% recommended N (80 kg ha^{-1}) combined with three foliar sprays of nano urea at tillering, jointing, and booting stages] is the most effective strategy for maximizing barley production in the Chitrakoot region. However, for farmers aiming to reduce conventional fertilizer use, T_6 [75 % N + 3 nano urea sprays (Tillering + Jointing + Booting Stage)] presents a viable and economically sustainable alternative. The adoption of nano urea technology is a step towards precision nitrogen management, ensuring higher productivity and farm income while promoting environmental sustainability.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/152270