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Optimised nitrogen management using nano and neem coated urea for improving growth, yield and economics of wheat (*Triticum aestivum*)

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ABSTRACT

The experiment was conducted during winter (*rabi*) seasons of 2022–23 and 2023–24 at ICAR-Indian Agricultural Research Institute, New Delhi to study the effect of different levels of nitrogen along with foliar applications of nano urea and neem-coated urea on growth, yield and economics of wheat (*Triticum aestivum* L.). The experiment was laid out in a randomised block design (RBD) with 15 treatments. These treatments combined basal nitrogen levels of 0, 50, 75, 100 and 125% of recommended nitrogen doses (RDN), along with foliar application of water spray (WS), nano-urea (NU) and neem-coated urea (NCU) in each level with 3 replications. The results demonstrated that treatments with reduced basal nitrogen, specifically with nano-urea application, achieved growth and yield comparable to the higher conventional dose of RDN. Foliar application of neem-coated urea along with 75% RDN produced significantly lower yield than RDN. However, 75% RDN + NU spray yielded 4.85 t/ha, which was at par with 100% RDN + WS (5.55 t/ha). Similarly, yield from 100% RDN + NU was equivalent to that of the 125% RDN treatments, regardless of the specific foliar spray applied. Under each level of RDN (125%, 100%, 75% and 50%), foliar application of nano-urea was a bit superior to neem-coated urea, though the differences were not significant. Yield attributes were also markedly improved with higher nitrogen doses and foliar sprays. The nano-urea had slightly higher total cost of cultivation over urea foliar application. However, among the treatments, 125% RDN + NU recorded significantly higher net return (1,33,909 ₹/ha) though it was at par with RDN. This two-year study showed that moderate nitrogen doses, especially in conjunction with nano-urea foliar treatments, can substantially enhance growth, yield attributes and yield, highlighting nano-fertilisers as a promising alternative for improving soil health, nutrient availability and yield, supporting more sustainable agriculture.

Keywords: Nano-urea, Neem-coated urea, Net return, Nitrogen levels, Yield attributes

Wheat (*Triticum aestivum* L.) is one of the world's most consumed cereal grains, along with rice (*Oryza sativa* L.) and maize (*Zea mays* L.) occupying a central position in the global food security framework. It provides approximately 20% of the world's dietary energy supply and is a major source of carbohydrates, protein, and essential nutrients (Shewry and Hey 2015). In India, it is grown on 31.78 mha and produced 112.92 mt during 2023–24 (ICAR-IIWBR 2024). However, to meet the projected wheat demand of 140 mt of the country by 2050, research must continue at the current pace with future research efforts would be focused on evolving new and innovative production technologies which can fit into the framework of changing wheat production scenarios (Singh *et al.* 2023). The productivity of wheat is influenced by a multitude of factors, with nitrogen (N) fertilisation as a key factor influencing wheat yield and quality. Although higher nitrogen fertiliser use has contributed to increased wheat yields (Shahane *et al.* 2023), excessive application has raised sustainability concerns, including yield stagnation and reduced farm profitability (Kumar *et al.* 2018). Thus, efficient nitrogen management is critical for maximising yields, resource use, and minimising environmental harm (Zhang *et al.* 2022).

Despite revolutionising crop production, conventional nitrogen use remains inefficient, with 50–70% lost via leaching, volatilisation, and denitrification, contributing to pollution and higher costs (Cameron *et al.* 2013). In addition to this, excessive nitrogen usage also leads to greenhouse gas emissions (e.g. N_2O) and potential health hazards (Aryal *et al.* 2022). To address these issues, nano-fertilisers and neem-coated urea (NCU) offer improved

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nitrogen use efficiency (NUE) through controlled release and better uptake (Suman *et al.* 2023). Nano-fertilisers, due to their small particle size, increase the surface area for interaction, resulting in faster absorption by plants and reduced nutrient loss. Nano-fertilisers, with high surface area and rapid absorption, reduce losses and enhance productivity (6–17%) and nutritional quality (Kumar *et al.* 2021b). Given wheat's high N demand, these technologies show strong potential. Previous studies have demonstrated that nitrogen application not only improves vegetative growth but also enhances yield-attributing factors such as the number of grains/earhead, grain weight, and overall biomass (Subedi *et al.* 2007). This study aimed to evaluate the effects of different nitrogen levels supplemented with foliar treatments on wheat growth, yield, and yield-attributing characters, with a focus on the comparison between nano-based and neem coated urea (NCU) treatments.

MATERIALS AND METHODS

Experiment site and treatments details: The experiment was conducted during the winter (*rabi*) seasons (2022–23 and 2023–24) at ICAR-Indian Agricultural Research Institute (28°38′ N, 77°09′ E; at an elevation of 229 m amsl), New Delhi to evaluate the effects of nitrogen levels with nano-urea (NU) and neem-coated urea (NCU) foliar sprays on wheat growth, yield, yield-attributing traits, and economics. The soil was sandy loam, well-drained, and levelled. Pre-sowing soil analysis revealed a mildly alkaline *p*H (7.8), low organic carbon (0.41%) and available N (149.6 kg/ha), medium available P (13.9 kg/ha), and high available K (313.4 kg/ha). The region has a semi-arid, subtropical climate, with temperatures ranging from 4.3–20.8°C in January to 19.1–40°C in May. Annual rainfall averages 651 mm, about 75% of which occurs during the southwest monsoon (July–September).

The experiment was laid out in a randomised block design (RBD) having 15 treatments, viz. T_1, Control (water spray); T_2, Two nano-urea foliar sprays (NUFS); T_3, Two neem-coated urea foliar sprays (NCUFS); T_4 50% recommended dose of nitrogen (RDN) + water spray (WS); T_5, 50% RDN + Two NUFS; T_6, 50% RDN + Two NCUFS; T_7, 75% RDN + WS; T_8, 75% RDN + Two NUFS; T_9, 75% RDN + Two NCUFS; T_{10}, 100% RDN + WS; T_{11}, 100% RDN + Two NUFS; T_{12}, 100% RDN + Two NCUFS; T_{13}, 125% + WS; T_{14}, 125% + Two NUFS and T_{15}, 125% + Two NCUFS, each treatment was replicated thrice. Wheat variety HD 3086 was sown on 17th November 2022 and 10th November 2023 using a tractor-drawn seed drill at 20 cm row spacing and a seed rate of 100 kg/ha, and harvested on 7th April 2023 and 1st April 2024, respectively. Foliar sprays were applied at tillering (30 DAS) and jointing (60 DAS) stages. Soil-applied fertilisers included urea (N), single superphosphate (P), and muriate of potash (K), with a recommended dose of 150 kg N, 60 kg P_2O_5, and 40 kg K_2O/ha. One-third of nitrogen was applied as basal, with the remaining two-thirds split equally at crown root initiation and active tillering stages. The nano-urea (an IFFCO product) containing 4% N (500 mL commercial pack) as encapsulated nitrogen analogues was used as a source of nano-urea. Foliar application of NU (0.4% N) was done at 4 mL/L while conventional urea was used at 2% concentration (20 g/L). Growth parameters were recorded periodically, and yield attributes and yield were measured at harvest.

Observations recorded: Data were collected on dry matter accumulation, grain yield, straw yield and yield attributes. Dry matter was recorded at 30, 60, and 90 days after sowing (DAS) and at harvest. Grain and straw yields were estimated from the net plot area and expressed in t/ha. Yield attributes were recorded at maturity using standard protocols. The harvest index (HI) was calculated as:

$$HI = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

Economics: Total production cost/ha was calculated using current market prices of inputs (seeds, fertilisers, insecticides including nano-urea) and labour wages. Gross return was computed using local market prices for wheat grain and straw. Net return was obtained by subtracting total cost from gross return. The most profitable treatment was identified based on the B:C ratio. The benefit-cost (B:C) ratio was calculated as:

$$\text{B:C ratio} = \text{Net return/ Cost of cultivation}$$

Statistical analysis: The data from two seasons were statistically analysed following the guidelines of Gomez and Gomez (1984). Statistical significance was determined using an F-test with a critical difference (CD) of 0.05 probability level. MS Excel was used for basic statistical interpretation, and preparation of figures.

RESULTS AND DISCUSSION

Dry matter accumulation: The dry matter accumulation (DMA) of the treated crops was measured at 30, 60, and 90 days after sowing (DAS) and at harvest. Across both growing seasons, the highest dry matter accumulation per m^2 was observed with the application of 125% RDN + Two NU sprays, with values of 1158.4 g at harvest (Fig. 1). However, this treatment was comparable with the application of 125% RDN + two NCU foliar spray which was at par with the result obtained with 100% RDN + Two water spray. Treatments receiving NU with lower basal dose produced comparable results with conventional higher basal dose treatments. These results are in conformity with Ullasa *et al.* (2016) and Reddy *et al.* (2018). Increased dry matter accumulation with increasing N application might be due to adequate nutrition obtained from higher nitrogen application levels.

Yield attributes: The data on earhead/m^2, grains/earhead, spike length, 1000-grain weight were influenced by the combined application of conventional and NU or NCU (Table 1). The number of earheads/m^2 increased significantly with higher nitrogen doses and the application of nano and neem-coated urea foliar sprays. The highest values were

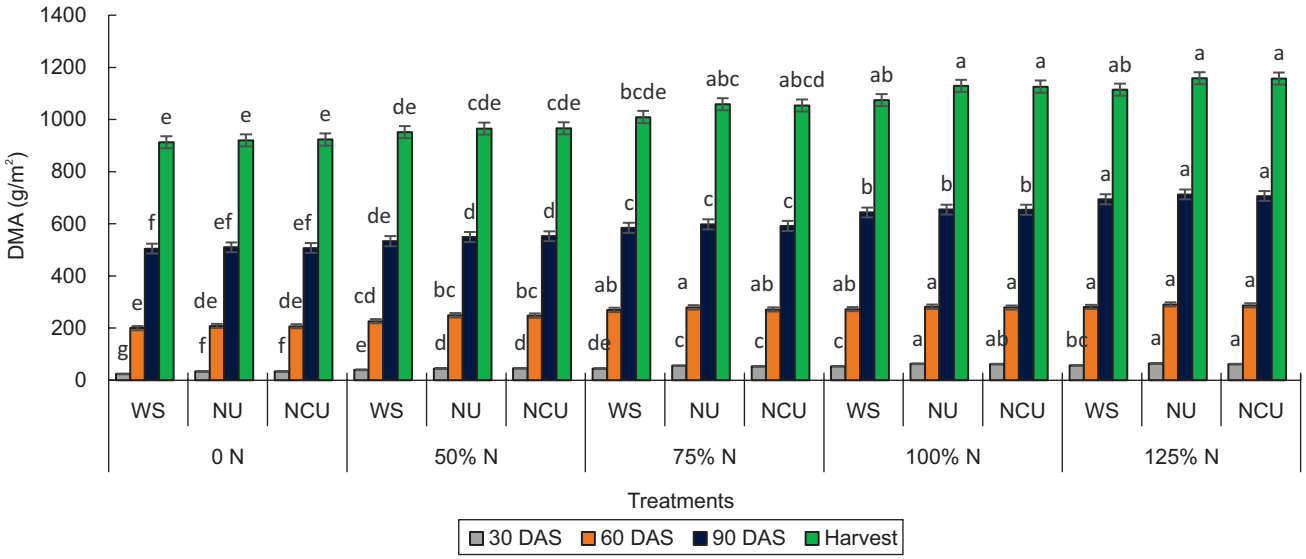

Fig. 1 Effect of different levels of nitrogen (N) with foliar application of nano and neem coated urea on dry matter accumulation (DMA) of wheat (mean data of two years).
WS, Water spray; NU, Nano urea; NCU, Neem coated urea; DAS, Days after sowing.

recorded in treatment 125% RDN + two NU foliar sprays with 330 earheads/m² followed by NCU spray and 100% RDN + water spray. However, these treatments were at par. This suggested that the higher nitrogen doses, particularly with nano-urea, have a positive influence on the production of earheads/unit area. The application of nano-urea, known for its higher absorption and utilisation efficiency, significantly enhanced tiller production. Similar findings were reported by Al-Juthery *et al.* (2018) and Ojha *et al.* (2023). Nitrogen plays a key role in tiller formation, and nano formulations, due to their efficient nutrient delivery, improve nitrogen use efficiency, leading to increased tiller numbers. Kumar *et al.* (2020) and Kumari *et al.* (2024) also observed enhanced tiller counts with nano-fertiliser application.

Table 1 Effect of different levels of urea with foliar spray of nano and neem coated urea on yield attributes and yield of wheat (mean data of two years)

Treatments	Earhead/ m^2	Grains/ earhead	1000 Grain weight (g)	Ear length (cm)	Spikelets/ spike	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	Harvest index
Control (water spray)	247.10^{d}	35.23^{f}	37.97	7.65^{e}	16.55	3.40^{h}	5.20^{f}	8.60^{h}	0.40
Two NU FS	258.62^{bcd}	35.90^{f}	38.80	8.40^{cde}	17.25	3.75^{fgh}	5.80^{ef}	9.55^{fgh}	0.39
Two NCU FS	254.46^{cd}	36.33^{ef}	38.45	8.35^{de}	17.40	3.65^{gh}	5.70^{ef}	9.35^{gh}	0.39
50% RDN + WS	258.62^{bcd}	39.60^{de}	39.26	8.80^{cd}	17.25	4.05^{efg}	5.90^{ef}	9.95^{efg}	0.41
50% RDN + Two NU FS	268.44^{bcd}	41.25^{bcd}	40.35	9.05^{cd}	17.95	4.30^{cdef}	6.25^{e}	10.55^{ef}	0.41
50% RDN + Two NCU FS	262.29^{bcd}	40.50^{cd}	39.71	8.95^{cd}	18.00	4.25^{def}	6.40^{e}	10.65^{de}	0.40
75% RDN + WS	271.25^{bcd}	41.07^{bcd}	40.60	9.15^{bc}	18.25	4.45^{cde}	7.20^{d}	11.65^{cd}	0.38
75% RDN + Two NU FS	288.08^{b}	43.30^{abc}	41.69	9.95^{a}	18.55	4.85^{c}	7.65^{cd}	12.50^{c}	0.39
75% RDN + Two NCU FS	277.95^{bc}	42.35^{abcd}	41.37	9.85^{ab}	18.40	4.65^{cd}	7.45^{d}	12.10^{c}	0.38
100% RDN + WS	321.58^{a}	42.15^{abcd}	41.90	9.85^{ab}	18.80	5.55^{bc}	8.30^{bc}	13.85^{b}	0.40
100% RDN + Two NU FS	326.62^{a}	44.90^{a}	42.95	10.20^{a}	19.35	6.00^{ab}	8.60^{ab}	14.60^{ab}	0.41
100% RDN + Two NCU FS	323.59^{a}	43.50^{abc}	42.80	10.05^{a}	19.05	5.90^{ab}	8.45^{ab}	14.35^{ab}	0.41
125% RDN + WS	325.40^{a}	43.55^{abc}	42.65	10.10^{a}	19.10	5.95^{ab}	8.90^{ab}	14.85^{ab}	0.40
125% RDN +Two NU FS	330.16^{a}	44.90^{a}	43.10	10.45^{a}	20.00	6.15^{a}	9.15^{a}	15.30^{a}	0.40
125% RDN + Two NCU FS	328.97^{a}	44.00^{ab}	42.90	10.25^{a}	19.70	6.05^{ab}	9.05^{ab}	15.10^{a}	0.40
SEM±	10.36	1.13	1.68	0.27	0.70	0.20	0.75	1.05	0.02
LSD ($p \leq 0.05$)	30.02	3.28	NS	0.77	NS	0.57	0.26	0.36	NS

WS, Water spray; NUFS, Nano-urea foliar spray; NCU FS, Neem-coated urea foliar spray; RDN, Recommended dose of nitrogen; NS, Non-significant.

Other yield attributes such as the number of grains/earhead, thousand grain weight, ear length, and spikelets/spike also followed this trend. The highest values were recorded under the treatment with 125% RDN + two nano-urea sprays, which were statistically comparable to treatments with at least 100% RDN applied through conventional urea (Table 1). These improvements were attributed to better nutrient availability and enhanced nitrogen use efficiency from nano urea (Reddy *et al.* 2018, Gokul and Senthilkumar 2021, Kumar *et al.* 2021a).

Yield: The grain yield showed a significant positive response to increased nitrogen levels and the foliar application of nano-urea (NU) and neem-coated urea (NCU). The highest yield 6.15 t/ha was recorded under the treatment with 125% RDN + two NU sprays, which was statistically at par with other treatments receiving 125% or 100% RDN along with any foliar spray (Table 1). In contrast, 75% RDN + NCU spray produced significantly lower yields than the full RDN treatment. However, the treatment with 75% RDN + NU spray yielded 4.85 t/ha, which was comparable to 100% RDN + WS (5.55 t/ha). Across all RDN levels (125%, 100%, 75%, and 50%), nano-urea consistently outperformed neem-coated urea, although the differences were not statistically significant. These consistent yield improvements highlighted the role of nano-urea in enhancing nitrogen availability and nutrient use efficiency. Its small particle size facilitates better foliar absorption and nutrient uptake, contributing to improved growth and grain production (Iqbal 2019). However, the yield advantage over NCU was not statistically significant, likely due to the lower nitrogen concentration in nano urea, which may have limited its effect on yield attributes (Rawate *et al.* 2022, Saklani and Pal 2023).

Similar trends were observed in straw yield where 125% and 100% RDN were at par yield irrespective of the foliar spray. The application of 75% RDN + nano-urea spray produced 7.65 t/ha straw yield, which was at par with 100% RDN. Foliar sprays of nano-urea, especially at higher nitrogen levels, promoted better vegetative growth, leading to increased straw biomass. The harvest index (HI) remained relatively consistent across treatments, with values ranging from 0.39–0.41. Under sufficient soil nitrogen, both prilled urea and NU foliar applications proved to be highly effective for the crop. These findings are consistent with Mehta and Bharat (2019). NU is releasing nitrogen twelve times slower than the conventional urea and thus is available over a longer period for functional metabolic interaction (Saurabh *et al.* 2019, Upadhyay *et al.* 2023). Al-Juthery *et al.* (2019), also observed an increase in yield when using nano-fertilisers. Overall, soil-applied nitrogen was the primary determinant of both grain and straw yield, with foliar urea or nano-urea serving as effective supplementary measure.

Relationship between dry matter accumulation and grain yield: Linear regression analysis was conducted to determine the response relationship between grain yield and dry matter accumulation at harvest for both seasons.

Table 2 Economics of different rates of nitrogen combined with foliar application of nano and neem coated urea (mean data of two years)

Treatments	Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B:C ratio
Control (water spray)	40,000	101,637.8	61,637.8	1.54
Two NU FS	41,124	112,455.8	71,331.8	1.73
Two NCU FS	40,108	109,782.5	69,566.5	1.73
50% RDN + WS	42,878	119,275.2	76,397.6	1.78
50% RDN + Two NU FS	44,002	126,565.0	82,563.4	1.88
50% RDN + Two NCU FS	42,986	126,431.5	83,337.8	1.93
75% RDN + WS	44,317	135,232.5	90,915.2	2.05
75% RDN + Two NU FS	45,441	146,321.9	100,880.7	2.22
75% RDN + Two NCU FS	44,425	140,927.5	96,394.25	2.16
100% RDN + WS	45,755	164,696.3	118,941.1	2.60
100% RDN + Two NU FS	46,879	175,855	128,975.8	2.75
100% RDN + Two NCU FS	45,863	172,885	126,913.8	2.76
125% RDN + WS	47,194	176,602.4	129,408.4	2.74
125% RDN + Two NU FS	48,318	182,227.2	133,909.2	2.77
125% RDN + Two NCU FS	47,302	179,548.4	132,138.4	2.79
SEM±	-	4,712.523	4,712.523	0.10
LSD ($p \leq 0.05$)	-	13,651.64	13,651.64	0.30

WS, Water spray; NUFS, Nano-urea foliar spray; NCU FS, Neem-coated urea foliar spray; RDN, Recommended dose of nitrogen.

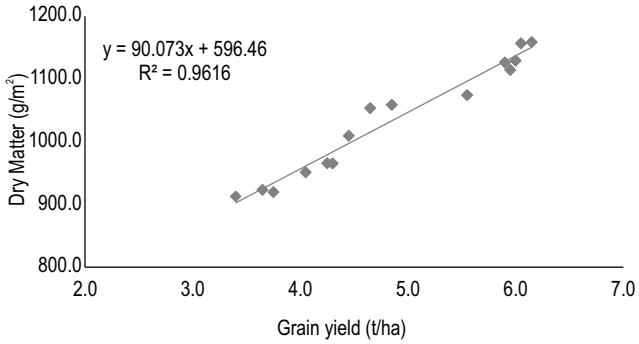

Fig. 2 Relationship between wheat grain yield and dry matter accumulation.

A strong and consistent positive correlation was observed, indicating that higher dry matter accumulation at harvest was closely associated with increased grain yield (Fig. 2). This significant relationship underscored the direct influence of biomass accumulation on yield, making it a critical trait for agronomists and breeders targeting yield enhancement. These findings are in agreement with Kaur *et al.* (2017), who also reported a significant association between grain yield and growth parameters such as dry matter accumulation, LAI, effective tillers/m², ear length, and grains/ear in wheat.

Economics: The nano-urea treatments had slightly higher total cost of cultivation over urea foliar application. However, among the treatments, 125% RDN + Two sprays of NU recorded significantly higher net return of 1,33,909.2 ₹/ha, though it was at par with RDN (Table 2). Due to lower cost of cultivation, 125% RDN + Two sprays of NCU recorded a bit higher benefit:cost (B:C) ratio of 2.79 which was at par with the NU applied treatment as well as with RDN. Due to higher yields obtained under these two treatments as compared to extra cost involvement, it recorded higher net return and B:C ratio over the other treatments.

This study clearly demonstrated that the application of nano-urea had a positive impact on wheat yields, particularly when it is applied with 75% and 100% recommended dose of nitrogen and it produced almost equal yield to foliar application of NCU. Applying 75% basal dose of nitrogen along with two foliar spray of nano-urea produced slightly lower yield as obtained from the 100% or 125% basal + NU, NCU or water spray, however, it was at par with these treatments. Thus, 25% of the RDN can be saved with the foliar application of NU with 75% RDN.

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