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Nano Urea as Sustainable Nutrient Strategy for Improving Phenological Traits, Quality and Soil Fertility in Wheat in semi-arid Regions of Haryana

Simran Sindhu, Rajesh Kathwal[1], Anita Kumari[2], Ram Prakash[3], Danveer Singh[3] and Ritika Dagar[4]

Department of Agronomy, College of Agriculture, CCS HAU, Hisar-125 004, India
[1]Regional research station (Horticulture), Buria, Yamunanagar-135 101, India
[2]Department of Botany & Plant Physiology, [3]Department of Soil Science,
[4]Department of Horticulture, College of Agriculture, CCS HAU, Hisar-125 004, India
E-mail: simransindhu2000@gmail.com

Abstract: The field experiment was conducted during *Rabi* 2023-24 at CCS Haryana Agricultural University, Hisar, to assess the impact of nano urea on growth, physiology, grain quality, and soil properties in wheat. The study used a split-plot design with three varieties (WH 1270, DBW 222, DBW 303) and four nutrient levels: 100% RDN, 100% RDN + one foliar spray of nano urea @ 4 mL L^{-1} (45 DAS), 75% RDN + two sprays (45 and 65 DAS), and 50% RDN + three sprays (30, 60, and 90 DAS). Wheat phenology and physiology responded significantly to. WH 1270 with longest crop duration, while 75% RDN + two sprays extended grain filling. Maximum chlorophyll (53.88 SPAD) and relative water content (91.35%) were observed under 100% RDN + one spray and 50% RDN + three sprays, respectively. DBW 303 produced the best grain quality with highest protein (13.12%), sedimentation value (43.58 mL), and hectolitre weight (82.74 kg hL^{-1}). Post-harvest soil analysis showed maximum available nitrogen (148.64 kg ha^{-1}) and phosphorus (17.71 kg ha^{-1}) under 100% RDN + one spray. Soil pH, EC, and organic carbon remained stable. The study suggests nano urea enhances nitrogen efficiency and supports sustainable wheat production under semi-arid conditions.

Keywords: Foliar spray, Protein content, Chlorophyll Content, DBW 303, Soil fertility

Wheat (*Triticum aestivum* L.) is one of the most widely cultivated and consumed cereal crop globally, serving as a major source of carbohydrates and protein for more than a third of the world's population (FAO 2023). In India, wheat occupies a central role in food security, cultivated across over 30 million hectares with significant contributions from northwestern states like Punjab, Haryana, and Uttar Pradesh (Ministry of Agriculture & Farmers Welfare 2023). To meet rising food demands and sustain soil health under climate stress, there is a growing emphasis on optimizing crop nutrition through precise and efficient fertilizer management.

Nitrogen (N) is a vital macronutrient that influences multiple aspects of wheat growth, including leaf expansion, chlorophyll synthesis, grain protein content, and ultimately, yield (Chen et al., 2022). However, conventional nitrogen fertilizers such as urea suffer from low nitrogen use efficiency (30–50%), with a substantial fraction lost through volatilization, leaching, and denitrification (Zhang et al., 2021). This inefficiency not only increases production costs but also contributes to environmental degradation and soil quality decline. To address these limitations, nano fertilizers, particularly nano urea have emerged as an innovative solution. Nano urea is a liquid formulation developed using nanotechnology with particles typically less than 50 nm in size and high surface area to volume ratio enables rapid absorption through leaf stomata, reduces nitrogen losses, and allows for targeted delivery during critical crop growth stages (Tarafdar et al., 2021, Singh et al., 2023). These properties contribute to improved nitrogen use efficiency, better synchronization with plant demand, and enhanced physiological and phenological responses.

Phenological traits such as days to heading, anthesis, maturity, and grain filling duration are critical in determining wheat adaptability, resource use efficiency, and final yield potential. Timely and balanced nitrogen availability can influence the onset and duration of key growth stages, allowing for better grain filling and harvest index (Rathore et al., 2023). Foliar nano urea applied at booting or heading stage has accelerate crop maturity while extending grain filling under limited basal nitrogen input (Kumar et al., 2022). In parallel, physiological parameters such as chlorophyll content (SPAD value) and relative water content (RWC) serve as sensitive indicators of nitrogen availability and plant health. Nano urea has been reported to sustain higher chlorophyll levels during reproductive stages and improve RWC, thereby supporting photosynthesis and drought resilience (Gao et al., 2020, Meena et al., 2022). From a quality perspective, nitrogen fertilization plays a central role in determining grain protein content, sedimentation value (a proxy for gluten strength), and hectolitre weight, all of which are key determinants for market and processing suitability. Adequate and timely nitrogen supply especially via foliar nano urea can boost protein synthesis during grain filling, enhance gluten formation, and improve test weight, thereby elevating wheat quality (Al-Juthery et al., 2019, Burhan and Al-Hassan 2020). Traditional urea application often leads to nutrient depletion and organic carbon loss, contributing to long-term fertility issues. Nano urea, owing to its lower required dosage and higher efficiency, can maintain or even improve post-harvest levels of available nitrogen, phosphorus, potassium, and organic carbon while minimizing environmental risks (Lal et al., 2020, Singh and Ameta 2022). Despite growing evidence of the agronomic benefits of nano urea, comprehensive field studies assessing it impact on phenological, physiological, grain quality, and soil parameters in India remain limited. Additionally, varietal responses to nano urea under varying nitrogen regimes are not well understood. Therefore, this study aimed to evaluate the effects of nano urea on wheat phenology (physiological traits), grain quality and post-harvest soil properties

MATERIAL AND METHODS

Experimental site and climate: The field experiment was conducted during the *Rabi* season of 2023–24, Chaudhary Charan Singh Haryana Agricultural University), Hisar, Haryana, India (29°14′N latitude, 75°68′E longitude; 215.2 m above mean sea level). The region is characterized by a semi-arid subtropical climate with hot summers and cool winters. During the cropping period, weekly mean maximum temperatures ranged from 13.9°C to 37.4°C, and minimum temperatures ranged from 4.1°C to 19.1°C. Total rainfall during the growing season was negligible (0.25 mm), and irrigations were scheduled as per crop requirements (Fig. 1).

Soil characteristics: The experimental soil was sandy loam in texture, alkaline in reaction (pH 7.89), with low electrical conductivity (EC 0.25 dS m^{-1}). It had low organic carbon (0.42%) and was moderately fertile with available nitrogen (142.5 kg ha^{-1}), phosphorus (17.56 kg ha^{-1}), and potassium (254.32 kg ha^{-1}). Soil sampling was done before sowing and post-harvest (0–15 cm depth).

Experimental design and treatments

The experiment was laid out in a split-plot design with three replications and twelve treatments (Table 1). Each treatment plot measured 3 m × 5 m (15 m²). The recommended dose of NPK was 150: 60: 60 kg ha^{-1}, and $ZnSO_4$ @ 25 kg ha^{-1} was applied as basal. Urea was used as the nitrogen source. Nano urea used in this study was sourced from IFFCO (Indian Farmers Fertiliser Cooperative Limited). It is a patented liquid formulation containing 4% w/v nitrogen with nano-sized particles (20–50 nm) designed for foliar absorption.

Table 1. Treatment structure used in the field study

Designation	Varieties
Main plot (Wheat varieties)	
V_1	WH 1270
V_2	DBW 303
V_3	DBW 222
Sub-plot (Nutrient levels)	
T_1	100% Recommended Dose of Nitrogen (RDN)
T_2	100% RDN + 1 spray of nano urea @ 4 mL L^{-1} at 45 DAS
T_3	75% RDN + 2 sprays of nano urea @ 4 mL L^{-1} at 45 and 65 DAS
T_4	50% RDN + 3 sprays of nano urea @ 4 mL L^{-1} at 30, 60, and 90 DAS

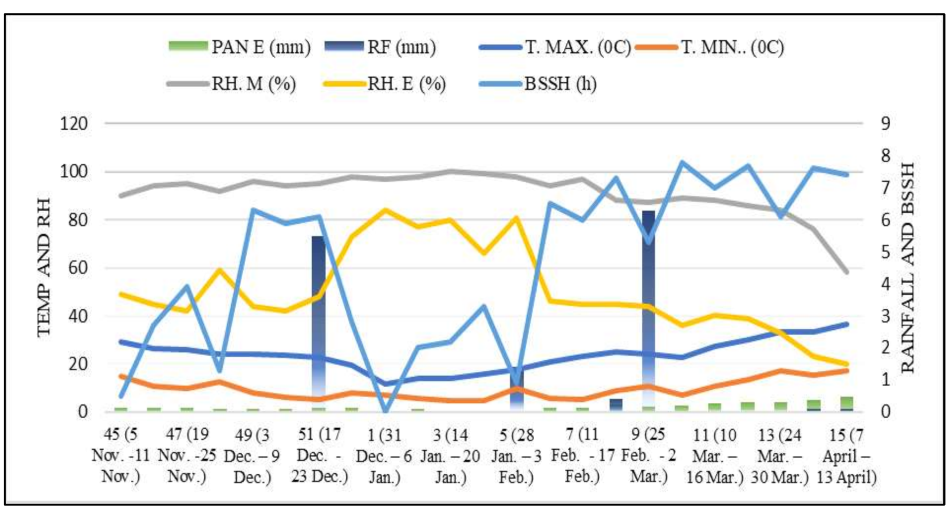

Fig. 1. Mean weekly meteorological data during the crop growing season 2022-23 at experimental area, CCS HAU, Hisar

Crop management: Wheat was sown on November 5, 2023, using behind-the-plough method at a row spacing of 22.5 cm. Half of the nitrogen and the full doses of phosphorus, potassium, and zinc were applied at sowing. The remaining nitrogen was top-dressed at the first irrigation (27 DAS). Foliar sprays were applied using a flat-fan nozzle at a concentration of 4 mL L^{-1} of water, as per treatment schedules. Sprays were conducted in the early morning or late afternoon to avoid rapid evaporation and ensure maximum leaf absorption. No other foliar fertilizers were mixed during application. Irrigations were applied at CRI, tillering, booting, heading, and dough stages. Standard agronomic practices were followed for weed, pest, and disease management. The crop was harvested on April 15, 2024.

Sample collection and analysis: Days to 50% heading, anthesis, and maturity were recorded y when 50% of the plants in each plot had reached the respective stage. Chlorophyll content was measured using a SPAD-502 chlorophyll meter on the flag leaf three days after each foliar spray of nano urea on the crop (30, 45, 60, 65, and 90 DAS). Relative Water Content (RWC) was measured using the formula:

$$RWC\ (\%) = (FW - DW)/ (TW - DW) \times 100$$

where FW = fresh weight, TW = turgid weight, and DW = dry weight of leaf samples .Samples for RWC were also collected three days after each foliar spray of nano urea at 30, 45, 60, 65 and 90 DAS. Protein content (%) was calculated by estimating nitrogen content using the Kjeldahl method and multiplying by the factor 6.25. Sedimentation value (mL) was determined using SDS-lactic acid test method. Hectolitre weight (kg hL^{-1}) was recorded using a standard hectolitre weight apparatus. pH (Jackson, 1973) and EC were measured from a 1: 2.5 soil-water suspension using digital meters (Richards, 1954). Organic carbon (OC) was analysed using the Walkley and Black method. Available N, P, and K were determined using alkaline $KMnO_4$, Olsen's, and flame photometry methods, respectively.

Statistical analysis: Data analysis was done by using "OPSTAT" software available at official website of CCSHAU, Hisar. (https://www.hau.ac.in/page/o-p-stat)

RESULTS AND DISCUSSION

Phenological parameters: Phenological stages were significantly influenced by both wheat varieties and fertility treatments (Table 2). Among varieties, V_1 took the maximum number of days to reach heading (84.3 days), anthesis (88.1 days), and maturity (138.3 days), indicating a longer growth period. In contrast, V_3 exhibited the earliest flowering (87.67 days) and maturity (147.33 days), making it more suitable for short-duration environments. Regarding nitrogen levels, T_4 had longstanding period for heading (74.56 days), anthesis (94.64 days), and maturity (157.22 days) due to extended vegetative growth induced by prolonged nitrogen availability. The T_1(100% RDF (150 kg N + 60 kg P_2O_5 + 60 kg K_2O + 25 kg $ZnSO_4$) and T_2 (100% RDN + one spray of nano urea at 45 DAS @ 4 ml/l of water) led to earlier phenological progression, promoting faster crop maturation and potentially avoiding terminal heat stress. Rathore et al. (2023) and Kumar et al. (2022), also observed that that foliar nano urea modulates hormonal and metabolic pathways associated with wheat phenology.

Physiological Parameters: Physiological responses were strongly impacted by nano urea applied through foliar feeding. The maximum SPAD value at 45 DAS (53.88) was in T_2 i.e. 100% RDN + one spray of nano urea at 45 DAS @ 4 ml/l of water, affirming enhanced chlorophyll biosynthesis due to improved foliar nitrogen absorption. However, at later

Table 2. Effect of different wheat varieties on phenological traits

Treatments	Phenological parameters		
Varieties	Days to heading	Days to anthesis	Days to maturity
V_1: WH 1270	73.10	92.72	158.08
V_2; DBW 303	72.83	93.13	157.50
V_3; DBW222	70.75	87.67	147.33
CD (p=0.05)	0.39	2.86	2.79
N levels			
N_1: 100% RDN	70.78	87.42	152.33
N_2: 100% RDN + 1 foliar spray of NU at 45 DAS	71.11	90.64	153.11
N_3: 75% RDN + 2 foliar sprays of NU at 45 and 65 DAS	73.00	91.98	154.56
N_4: 50% RDN + 3 foliar sprays of NU at 30, 60 and 90 DAS	74.56	94.64	157.22
CD (p=0.05)	0.71	1.59	1.75

stages (60–90 DAS), T_4 maintained higher chlorophyll content, (51.98) at 65 DAS and (41.94) at 90 DAS, reflecting a prolonged greening effect of nano urea and enhanced nitrogen uptake and sustained photosynthetic activity (Table 3). Gao et al. (2020) and Meena et al. (2022), also observed increased chlorophyll retention and delayed senescence in nano urea-treated wheat plants. Varietal effect on chlorophyll content was non-significant at all crop growth stages. However, numerically, higher values were exhibited by WH 1270 at all crop growth stages. In general, chlorophyll content decreased with increasing age of crop.

In terms of relative water content (RWC), WH 1270 consistently outperformed DBW 222 and DBW 303, likely due to better water retention and physiological adaptation. The highest RWC (97.07%) at 45 DAS was also observed in T_2, while T_4 sustained higher RWC during later growth stages (60–90 DAS), *viz.,* 86.87, 84.88 and 78.17% at 60, 65 and 90 DAS respectively, supporting prolonged metabolic activity under reduced nitrogen input (Table 4). Elevated RWC suggests improved cell turgor and water-use efficiency, likely due to better osmotic regulation facilitated by nitrogen-enhanced metabolism (Tarafdar et al., 2021).

Quality parameters: Nano urea treatments and varietal differences had significant impacts on grain quality traits (Table 5). Maximum protein content was in DBW 303 (13.12%) followed by WH 1270 (12.12%) which was at par with DBW 222. Among fertility treatments, T_3 produced the highest protein content (12.80%) and was statistically at par to T_4 . The variety DBW 303 showed significantly higher sedimentation value (43.58 ml) over WH 1270 and DBW 222 which were statistically at par to each other. T_3 showed highest sedimentation v (43.89 ml) and was statistically at par

Table 3. Effect of wheat varieties on chlorophyll content (SPAD value) at various crop stages

Treatments	Chlorophyll content (SPAD)				
Varieties	30 DAS	45 DAS	60 DAS	65 DAS	90 DAS
WH 1270	53.39	53.51	49.94	45.49	40.71
DBW 303	52.66	50.42	49.77	42.63	40.47
DBW222	52.92	47.91	49.66	41.99	39.42
CD (p=0.05)	NA	NA	NA	NA	NA
N levels					
N_1	53.69	47.41	47.31	40.98	38.32
N_2	53.63	53.88	50.86	42.93	39.78
N_3	52.23	51.58	49.02	45.28	40.77
N_4	52.42	49.58	51.98	44.29	41.94
CD (p=0.05)	0.98	4.65	0.56	2.61	1.36

See Table 2 for treatments details

Table 4. Effect of nano urea spray frequencies on relative water content at different crop growth stages

Treatments	Chlorophyll content (SPAD)				
Varieties	30 DAS	45 DAS	60 DAS	65 DAS	90 DAS
WH 1270	91.80	97.29	85.64	84.18	74.63
DBW 303	89.51	93.85	83.47	82.69	72.22
DBW222	91.28	95.04	84.62	82.20	73.44
CD (p=0.05)	0.47	1.24	1.37	0.81	1.79
N levels					
N_1	92.56	93.14	81.93	81.04	74.20
N_2	91.89	97.07	83.65	82.42	72.62
N_3	90.38	96.45	85.85	84.54	75.73
N_4	88.63	94.93	86.87	84.88	78.17
CD (p=0.05)	0.95	0.34	0.58	0.53	0.97

See Table 2 for treatments details

with T_2 (41.22 ml) and T_4 (42.22 ml). The improvement in protein content and gluten strength reflects efficient nitrogen assimilation during the grain filling period (Al-Juthery et al., 2019, Burhan and Al-Hassan 2020). Foliar nano urea, by directly supplying nitrogen to flag leaves, enhances amino acid synthesis and protein accumulation in grains (Ghafari and Razmjoo 2013). The analysis of data on hectolitre weight revealed significant difference as influenced by the spray of nano urea. Among varieties highest weight was r for DBW 303 (82.74 kg hL^{-1}), which was statistically at par with WH 1270). The highest nutrient response was observed in T_3 *i.e.* 82.94 kg hL^{-1} which was significantly higher than other nutrient levels. The lowest was recorded in T_1 (79.34 kg hL^{-1}). Higher hectolitre weight observed under nano urea treatments indicates better grain filling and density. Singh et al. (2023) also improved grain morphology and end-use quality with foliar nano nitrogen.

Soil parameters: Soil analysis post-harvest indicated that T_2 recorded the highest available nitrogen (148.64 kg ha^{-1}) and phosphorus (17.71 kg ha^{-1}), followed closely by other nano urea treatments (Table 6). Potassium levels remained unaffected across treatments. Soil pH, electrical conductivity, and organic carbon content showed no significant differences, indicating that nano urea did not adversely affect soil chemistry in a single season. Among varieties, DBW 222 maintained the highest soil nitrogen (145.59 kg ha^{-1}) and phosphorus (17.60 kg ha^{-1}), while all varieties showed comparable values for soil pH and EC. The enhanced residual nitrogen suggests reduced volatilization and better plant uptake efficiency (Tarafdar et al., 2021). Lal et al. (2020) and Singh & Ameta (2022), also emphasized that nano fertilizers reduce nutrient losses and contribute to long-term soil fertility sustainability. The stable pH and EC across treatments further demonstrate the environmental safety of

Table 5. Combined effect of wheat varieties and nano urea treatments on grain quality parameters

Treatments	Protein content (%)	Sedimentation value (ml)	Hectolitre weight (kg/hl)
Varieties			
WH 1270	11.63	40.67	78.97
DBW 303	13.12	43.58	82.74
DBW222	11.99	41.42	81.29
CD (p=0.05)	0.55	1.27	2.61
N levels			
N_1	11.57	40.22	79.34
N_2	11.86	41.22	80.71
N_3	12.80	43.89	82.94
N_4	12.76	42.22	81.00
CD (p=0.05)	0.46	1.95	1.75

See Table 2 for treatments details

Table 6. Post-harvest soil analysis showing the impact of wheat varieties and nano urea treatments on available N, P, K, soil pH, EC, and organic carbon

Treatments	Soil pH	Soil EC (dS/m)	Soil OC (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
Varieties						
WH 1270	7.87	0.24	0.43	139.47	17.59	256.46
DBW 303	7.76	0.24	0.42	142.49	17.44	253.79
DBW222	7.83	0.24	0.42	145.59	17.6	256.63
CD (p=0.05)	NS	NS	NS	4.13	0.05	NS
N levels						
N_1	7.81	0.24	0.41	144.06	17.63	255.78
N_2	7.82	0.25	0.44	148.64	17.71	258.56
N_3	7.83	0.25	0.42	143.68	17.46	254.83
N_4	7.81	0.24	0.42	137.68	17.37	253.33
CD (p=0.05)	NS	NS	NS	4.13	0.13	NS

See Table 2 for treatments details

nano urea, as no adverse effects on soil chemical properties were observed over the season.

CONCLUSION

The application of 75% + two foliar sprays of NU @ 4 mL L^{-1} at 45 and 65 DAS (T_3) emerged as the most effective strategy, achieving superior grain protein content (12.80%), sedimentation value (43.89 mL), and hectolitre weight (82.94 kg hL^{-1}), while also extending the grain filling duration (42.4 days). Physiologically, this treatment sustained high chlorophyll content and RWC, supporting prolonged photosynthetic activity. In terms of soil fertility, T_2 (100% RDN + 1 foliar spray of NU @ 4 mL L^{-1} at 45 DAS) maintained the highest available nitrogen and phosphorus levels, indicating the potential of nano urea to reduce nutrient losses and enhance residual fertility.

AUTHOR'S CONTRIBUTION

Data collection, data analysis, lab analysis, original draft preparation: Simran Sindhu, Supervision and Guidance: Rajesh Kathwal, Anita Kumari, Ram Prakash; Manuscript editing and revision: Ritika and Danveer Singh.

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