Journal of Advances in Biology & Biotechnology

Volume 27, Issue 9, Page 1477-1484, 2024; Article no.JABB.123168
ISSN: 2394-1081

Effect of Nano Urea on Growth, Yield and Nitrogen Use Efficiency of Irrigated Wheat (*Triticum aestivum* L.)

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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/jabb/2024/v27i91421

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://www.sdiarticle5.com/review-history/123168

Short Research Article

Received: 10/07/2024
Accepted: 12/09/2024
Published: 16/09/2024

ABSTRACT

In the rabi season of 2021-22, the investigation was conducted at Bihar Agricultural University Sabour, Bhagalpur (Bihar), to study the effects of nano urea on growth attributes, yield and nitrogen use efficiency of irrigated wheat (*Triticum aestivum* L.). Randomized block design (RBD) with

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Cite as: *Rani, Guriya, Himanshu Prakash, Goldee Kumari, Saurabh Kumar Choudhary, Seema, and Sushil Kumar Pathak. 2024. "Effect of Nano Urea on Growth, Yield and Nitrogen Use Efficiency of Irrigated Wheat (Triticum Aestivum L.)". Journal of Advances in Biology & Biotechnology 27 (9):1477-84. https://doi.org/10.9734/jabb/2024/v27i91421.*

thirteen treatments in three replications was used. Treatments involved different levels of nitrogen i.e- 0, 50, 75 and 100% of recommended dose of nitrogen (RDN) along with 5% urea solution and nano-urea applied at tillering and jointing stages. The results showed that 100% and 75% RDN with two sprays of nano urea significantly improved the yield attributes like plant height, Leaf area Index (LAI), test weight, dry matter accumulation and yield. This study gave the highest grain yield of 4573 kg h^{-1} for RDN + two spray of urea (5%) and 4492 kg h^{-1} from RDN + two spray of nano urea. The present study has also shown that application of 75% RDN with nano urea resulted in the highest NUE of 10.20 kg kg-1. This means that nano-urea can be used with conventional urea without an adverse effect on high productivity of wheat.

Keywords: Nano urea; urea spray 5%; levels of nitrogen; NUE; Bihar; irrigated wheat.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is a rabi (annual) crop in India, ranking first among global cereals. It has caryopsis type of fruit and its grain contains 78% carbohydrates, 11-12% protein, 1.80-2.00% fat, 1.8% minerals, and 2.20% fiber, along with essential vitamins such as vitamin A and B complex [1]. In India, wheat is cultivated across 31.45 million hectares, producing 107.59 million tons with a productivity of 3421 kg ha^{-1}. Bihar ranks 6th in cultivating wheat on 2.25 million hectares, producing 5.90 million tons, and a productivity of 2626 kg ha^{-1}. Traditional wheat cultivation heavily relies on urea as a nitrogen source, but its application often results in significant nitrogen losses due to leaching, volatilization, and denitrification [2], along with increased transportation costs due to its bulkiness. Thus, Nano Urea (particle size 20-50 nm) has emerged as an innovative and eco-friendly alternative, offering enhanced nutrient use efficiency, reduced cultivation costs because a 500 ml bottle of 4% (w/v) is equivalent to a 45 kg urea bag (Frank and Husted., 2024) and also improves crop yield and quality by getting easily absorbed through stomata and other openings on the leaves.

This study investigates the effects of Nano Urea on wheat growth, yield and nitrogen use efficiency in an irrigated wheat system, to signify the potential of nano urea as a sustainable solution for modern agriculture.

2. MATERIALS AND METHODS

The research was performed during the Rabi season of 2021-21 at the Research Farm of Bihar Agricultural University, Sabour (Bhagalpur) located in Agro-climatic Zone III A of Bihar. With coordinates- 25°50' N latitude and 87°19' E longitude and an elevation of 37.19 meters above mean sea level. The region experiences an average annual rainfall of 1167 mm. and January, being the coldest month of the year, recorded a minimum temperature range of 5 to 10 °C. The soil was characterized by low organic carbon content (0.46%), low available nitrogen (162.0 kg ha^{-1}), medium available phosphorus (22.54 kg ha^{-1}), and available potassium (151.0 kg ha^{-1}); having a pH of 7.5 and EC- 0.26 dS m^{-1}. The wheat variety DBW187 (Karan Vandana) was used for the study with a seed rate of 100 kg ha^{-1}, sown using Kera method with a row spacing of 20 cm. The experimental plots were ploughed twice using a power tiller followed by planking for making fine seed bed. Randomized Block Design is used in the experiment with three replications. For irrigation, check basin method was used twice (12 cm water is required) during entire cropping period, the first irrigation was applied 21 days after sowing (DAS) and the second irrigation was applied after 80 DAS. The RDF was applied at the rate of 150:60:40 kg ha^{-1} of N: P_2O_5: K_2O.

The experiment consisted of 13 different treatments. Treatment T1- involved recommended dose of nitrogen (RDN) combined with a water spray at tillering and jointing stages. Treatment T2- RDN + one spray of Nano Urea at the tillering stage. Treatment T3- RDN + two sprays of Nano Urea at tillering and jointing stages, Treatment T4- RDN + two sprays of 5% urea solution at the same growth stages. Treatment T5- reduced the nitrogen dose to 75% of RDN combined with a water spray at tillering and jointing stages, Treatment T6-75% RDN + one spray of Nano Urea at tillering. Treatment T7- 75% RDN + two sprays of Nano Urea at tillering and jointing stages, and Treatment T8- involved 75% RDN with two sprays of 5% urea solution at the both stages. Treatment T9- reduced the nitrogen dose to 50% of RDN combined with a water spray at tillering and jointing stages. Treatment T10- 50% RDN + one spray of Nano Urea at tillering stage, Treatment

T11 included 50% RDN + two sprays of Nano Urea at tillering and jointing. Treatment T12- 50% RDN with two sprays of 5% urea solution at the same stages, and Treatment T13- served as the control. 60 kg Phosphate (P_2O_5) ha^{-1} as SSP and 40 kg potash (K_2O) ha^{-1} as MOP were fully applied as a basal dose at the time of sowing. The recommended dose of nitrogen was applied in two splits as basal dose (at the time of sowing) and the remaining half as top dressing during the tillering and jointing stages.

Crop growth attributes were measured at 25, 50, 75, and 100 DAS. Plants' height was recorded from the base to top using a meter scale. The number of tillers meter -2 was counted for each plot. For dry matter accumulation, plants above 0.25 m were collected and dried in an oven at 60°C until a constant weight was achieved at each growth stage. Leaf area index (LAI) was determined using a Ceptometer, calculated as total leaf area (cm^2) $=\frac{Total\ leaf\ area\ (cm^2)}{ground\ area\ (cm^2)}$. and Crop growth rate (CGR) ground area (cm^2) reflecting the rate of biomass gain over time, was calculated using the formula: CGR (g m^{-2} day^{-1}) $=\frac{w2-w1}{t2-t1}$. Where, W2 and W1 are the final and initial dry weight of the crop at the time t2 and t1 respectively.

Yield attributes were measured at maturity stage, the number of ear head-bearing tillers was counted from four random area of 0.25 m^2 areas within the net plot, and that process was repeated during the crop's growth period to record tiller numbers. The length of the ear heads, excluding the awns, was studied from five tagged plants in each plot, and the average length was calculated in centimeters. To determine the grains per ear head, five ear heads from each plot were manually threshed, and the grains were counted to obtain an average number. Finally, after threshing and winnowing, a representative grain sample was taken from each plot, and 1,000 grains were randomly selected using a mechanical seed counter. Their total weight was then recorded in grams as test weight.

Yield of wheat crop was measured after harvesting and cleaning from each plot separately. The yield (grain) was calculated at 12% moisture content likewise for measuring straw yield, straw samples were dried to a constant weight and the dry weight data were then converted to kg ha^{-1}. Harvest index was derived by using the formula:

$$H.I. = \frac{Economic\ yield\ (grain\ yield)\ Kgha^{-1}}{Biological\ yield\ (grain + straw)} \times 100\ ;$$

expressed as percentage (%).

To measure the nutrient (NPK) uptake, plant samples from each treatment were collected and oven dried at 60 ± 5 ºC for 48 hours followed by grinding and sieving through a 30 mesh sieves. Estimation of the nitrogen content in wheat plant samples was done through modified Kjeldahl's method (Jackson, 1967). The tri-acid digested plant samples were used for estimating phosphorus content by vanadomolybdo phosphoric acid yellow colour method (Jackson, 1973). Potassium content of the extractant of tri-acid digested material was estimated using flame photometer. Thereafter the total nutrient content/uptake (grain and straw) was converted to kg ha^{-1} by multiplying percent content with the respective yields. Which is then used to measure the total NPK, using formula Total (NPK)= $\frac{\text{N+P+K content}}{3}$.For deriving Nitrogen Use Efficiency (NUE- Generally expressed as Kg Kg^{-1}) the formula used was;

NUE=

$$\frac{\text{Economic yield with nitrogen applied plot} - \text{Economic yield without nitrogen applied plot}}{\text{Total Nitrogen applied}}$$

Parameters were statistically analyzed using analysis of variance (ANOVA). The significance of treatment effects was computed with the help of 'F' (variance ratio) test and to judge the significance of differences between means of two treatments, critical differences (CD) was derived as described by Cochran and Cox [3] and Gomez and Gomez [4].

3. RESULTS AND DISCUSSION

3.1 Effects of Nano Urea on Growth Parameters of Wheat

The application of varying nitrogen levels combined with foliar sprays of nano urea and water, significantly influenced wheat crop growth parameters. The foliar spray of nano urea enhanced plant height, number of tillers, leaf area index (LAI) and dry matter accumulation throughout all growth stages. This improvement is attributed to the consistent availability of nitrogen during critical growth phases, such as tillering and jointing. The increased nutrient supply from nano urea supports various metabolic processes, enhancing physiological and biochemical functions that promote apical growth and expanded photosynthetic areas resulting from meristematic activities. The foliar application of nano nitrogen, which penetrates easily through stomata, increased nutrient uptake, boosting carbohydrate mobilization into amino acids and proteins, thereby stimulating rapid cell division and elongation. These findings align with studies by Sharma et al. [5], Rajasekar et al. [6], AL-Gym AJK and Al-Asady MHS [7], and Chandana [8].

The nitrogen levels significantly affected tiller density (tillers per square meter) across all growth stages, with a sharp increase observed between 25 and 75 days after sowing (DAS), followed by a decline towards maturity. Notably, the highest tiller density was recorded in treatments receiving recommended nitrogen doses (RDN) and two foliar sprays of nano urea during tillering and jointing stages, closely followed by treatments with RDN + two sprays of 5% urea. This sustained nutrient release from nano fertilizers positively impacted plant growth by maintaining a consistent nutrient supply, further confirmed by the increased nitrogen uptake and enhanced cell activities noted in similar studies.

Nitrogen's role in promoting cell division-elongation and tissue differentiation contributes to vegetative growth by increasing plant height and leaf size. A larger leaf area improves sunlight interception, leading to more assimilate production, thereby enhancing overall crop growth and development. These findings are consistent with the result of Bhanuchandar et al. [9], Choudhary et al. [10], Mandeewal et al. [11], and Rahman et al. [12], who reported that increase in dry matter accumulation was due to higher photosynthetic rates and larger leaf areas.

3.2 Effect of Nano Urea on Yield Attributes and yield

The economic yield of wheat is influenced by various components, including the number of ear heads meter-2, ear head length, grains per ear head, and 1000-grain weight. These yield attributes are developed during the vegetative phase, where healthy vegetative growth enables optimal expression of these characteristics. The yield of a crop reflects the aggregate effect of these attributes, which are influenced by both environmental conditions and genetic traits.

Table 1. Effect of nano urea on plant height, tiller count, leaf area index (LAI) and Crop growth rate (CGR) at the time of maturity.

Treatments		Plant height (cm)	No. of tillers m^{-2}	LAI	CGR
T_1	RDN + water spray	92.80	298.67	3.28	0.99
T2	RDN + one spray of nano urea	93.27	302.69	3.41	1.13
T3	RDN + two spray of nano urea	94.64	305.59	3.83	1.03
T4	RDN + two spray of urea (5%)	95.38	318.52	3.87	1.24
T_5	75 % RDN + water spray	85.12	288.85	2.71	1.86
T6	75 % RDN + one spray of nano urea	87.23	279.15	2.85	2.06
T7	75 % RDN + two spray of nano urea	88.92	282.90	3.00	3.25
T_8	75 % RDN + two spray of urea (5 %)	89.23	295.58	3.15	2.59
T9	50 % RDN + water spray	80.97	220.71	2.37	2.10
T10	50 % RDN + one spray of nano urea	81.58	232.38	2.44	2.33
T11	50 % RDN + two spray of nano urea	82.77	253.64	2.50	2.15
T12	50 % RDN + two spray of urea (5 %)	83.32	268.27	2.60	4.94
T13	Control	76.68	185.59	1.99	4.12
SEm (±)		2.93	12.21	0.24	1.14
CD at 5 %		8.55	35.63	0.71	NS

Table 2. Effect of nano urea on dry matter accumulation of wheat

Treatments		Dry matter accumulation (g m^{-2})				
		25 DAS	50 DAS	75 DAS	100 DAS	At maturity
T_1	RDN + water spray	83.66	237.85	375.38	532.01	556.82
T2	RDN + one spray of nano urea	81.34	243.31	380.61	533.33	561.67
T3	RDN + two spray of nano urea	83.55	245.09	387.19	540.96	566.77
T4	RDN + two spray of urea (5%)	79.49	249.01	393.72	555.52	571.19
T_5	75 % RDN + water spray	78.18	223.64	362.30	481.96	528.45
T6	75 % RDN + one spray of nano urea	78.75	230.91	364.89	487.30	538.71
T7	75 % RDN + two spray of nano urea	81.88	232.86	370.41	459.10	540.33
T_8	75 % RDN + two spray of urea (5 %)	81.14	242.12	373.63	497.08	561.78
T9	50 % RDN + water spray	76.69	190.74	340.38	415.63	468.15
T10	50 % RDN + one spray of nano urea	78.09	200.04	352.24	425.45	483.76
T11	50 % RDN + two spray of nano urea	77.92	208.30	357.17	436.96	490.77
T12	50 % RDN + two spray of urea (5 %)	80.09	215.41	358.82	371.93	495.55
T13	Control	80.22	179.35	292.17	318.77	421.89
SEm (±)		4.35	9.59	17.01	22.44	22.06
CD at 5 %		NS	28.00	49.64	65.49	64.38

***Two spray: 1st at tillering and 2nd at jointing stage*
***One spray: tillering stage*

Table 3. Effect of nano urea on yield attributes of wheat

Treatments		Ear head m-2	Grains ear head-1	1000- grain weight (g)	Spike length (cm)
T1	RDN + water spray	276.22	48.00	42.40	9.77
T2	RDN + one spray of nano urea	279.18	48.67	43.16	10.16
T3	RDN + two spray of nano urea	282.89	50.00	43.48	10.40
T4	RDN + two spray of urea (5%)	286.05	51.67	43.97	10.83
T5	75 % RDN + water spray	269.79	43.00	41.75	8.93
T6	75 % RDN + one spray of nano urea	272.79	47.00	42.22	9.00
T7	75 % RDN + two spray of nano urea	273.63	47.67	42.83	9.34
T_8	75 % RDN + two spray of urea (5 %)	286.73	48.33	42.98	9.40
T9	50 % RDN + water spray	252.53	46.00	39.68	6.50
T_{10}	50 % RDN + one spray of nano urea	253.16	46.67	40.22	7.00
T_{11}	50 % RDN + two spray of nano urea	253.96	46.00	41.12	7.43
T_{12}	50 % RDN + two spray of urea (5 %)	255.97	46.33	41.71	7.67
T_{13}	Control	200.38	43.67	34.63	6.00
SEm (±)		14.72	2.22	1.80	0.50
CD at 5 %		42.97	6.48	5.24	1.45

***Two spray: 1st at tillering and 2nd at jointing stage*
***One spray: tillering stage*

Experimental results indicate that increasing nitrogen levels and applying a 4% foliar spray of nano urea significantly enhance yield attributes such as ear head number and length, grains per ear head, and test weight. This improvement is likely due to the continuous nitrogen supply provided by nano urea at critical growth stages, promoting meristematic activity. Similar result was observed by Jassim et al. (2019). The elongation of ear heads may be attributed to nano urea's ability to enhance water and nutrient absorption, thereby improving photosynthesis. Additionally, nano-NPK acts as a biological pump, facilitating nutrient and water uptake, as reported by Wu M [13] and Ma et al. [14]. The increase in grains per ear head is likely due to the enhanced rate of assimilation followed by translocation of photosynthates from the leaves to grains, supported by timely nitrogen supply through foliar spray. This observation aligns with the findings of AL-gym AJK and Al-Asady MHS [7]. Test weight improvement is also linked to better water and absorption facilitated by nano-NPK, leading to enhanced photosynthesis, as observed by Wu [13].

The final yield of wheat, encompassing both grain and straw yield, varies significantly based on location. It is determined by the genotype's potential, the environmental conditions throughout the plant's life cycle, and agronomic management practices. Data shows that highest grain yield of 4492 kg ha^{-1} was recorded in treatment T3, where two nano urea sprays at tillering and jointing stages, along with 100% RDN, were applied. This yield was statistically similar to the highest yield of 4573 kg ha-1 obtained in treatment T4, which involved two sprays of a 5% urea solution at the same stages along with 100% RDN. The combination of nano fertilizers with traditional nitrogen fertilizers enhances nutrient absorption efficiency, photosynthesis, and nutrient translocation, ultimately boosting economic and biological yields. The observed increase in yield parameters due to nano urea spray aligns with the results of Kumar et al. [15], Khalil et al. [16], Ma et al. [14], and Liu and Liao [17].

Table 4. Effect of nano urea on grain yield, straw yield, biological yield and harvest index of wheat

	Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest Index (%)
T1	RDN + water spray	4210.00	5078.20	9288.20	45.29
T2	RDN + one spray of nano urea	4423.33	5098.32	9521.65	46.40
T3	RDN + two spray of nano urea	4492.33	5235.67	9728.00	46.08
T_4	RDN + two spray of urea (5%)	4573.33	5319.33	9892.67	46.25
T_5	75 % RDN + water spray	3927.33	5033.33	8960.67	43.72
T6	75 % RDN + one spray of nano urea	4030.00	5142.97	9172.97	43.98
T7	75 % RDN + two spray of nano urea	4116.67	5174.97	9291.64	44.29
T8	75 % RDN + two spray of urea (5 %)	4240.33	5230.68	9471.01	44.66
T_9	50 % RDN + water spray	3254.67	4244.80	7499.46	43.47
T_{10}	50 % RDN + one spray of nano urea	3391.67	4494.17	7885.84	43.30
T_{11}	50 % RDN + two spray of nano urea	3444.33	4533.33	7977.67	43.10
T_{12}	50 % RDN + two spray of urea (5 %)	3469.00	4606.67	8075.67	42.98
T_{13}	Control	2938.33	3809.00	6747.33	43.87
SEm (±)		148.43	194.87	268.96	1.63
CD at 5 %		433.23	568.79	785.05	NS

***Two spray: 1st at tillering and 2nd at jointing stage*
***One spray: tillering stage*

Table 5. Total Nutrient uptake and Nitrogen use efficiency as affected by nano urea

Treatments	Nutrient Uptake				Nitrogen Use Efficiency (Kg Kg^{-1})
	N	P	K	Total (NPK)	
T1 RDN + water spray	104.60	17.28	68.01	63.30	8.50
T2 RDN + one spray of nano urea	117.85	18.22	69.45	68.51	9.80
T3 RDN + two spray of nano urea	121.28	18.50	70.30	70.03	10.10
T4 RDN + two spray of urea (5%)	123.30	18.89	72.41	71.53	9.70
T5 75 % RDN + water spray	97.31	16.29	65.83	59.81	8.80
T6 75 % RDN + one spray of nano urea	109.52	16.53	67.87	64.64	9.60
T7 75 % RDN + two spray of nano urea	111.43	17.06	69.03	65.84	10.20
T8 75 % RDN + two spray of urea (5 %)	113.59	17.70	69.95	67.08	9.90
T9 50 % RDN + water spray	79.83	13.26	54.41	49.17	4.20
T10 50 % RDN + one spray of nano urea	86.08	14.07	58.20	52.78	5.90
T11 50 % RDN + two spray of nano urea	87.40	14.24	59.05	53.56	6.50
T12 50 % RDN + two spray of urea (5 %)	88.37	14.82	60.01	54.40	5.70
T13 Control	67.45	11.60	49.42	42.82	-
SEm (±)	3.11	3.11	2.15	4.56	1.32
CD at 5 %	9.07	9.07	6.28	13.30	3.9

3.3 Effect of Nano Urea on Nitrogen Use Efficiency (NUE)

Nano urea, a nanotechnology-based urea formulation, enhances nutrient use efficiency in crops by releasing nitrogen more slowly than traditional urea. This controlled release ensures a steady nutrient supply throughout the crop's growth period, improving overall nitrogen availability, especially when applied as a foliar spray. Due to their smaller size, nano urea particles are more easily absorbed through leaf pores, leading to better nutrient accumulation in plant vacuoles, which are released as needed. This synchronization of nitrogen availability with the crop's nitrogen demand significantly boosts nitrogen use efficiency (NUE). Research by Liscano et al. [18] supports these findings, emphasizing that the timing of nitrogen application is crucial for maximizing crop uptake and minimizing losses. In one study, the highest NUE (10.2 kg ha^{-1}) was observed in a treatment combining 75% of the recommended nitrogen dose with two foliar sprays of 4% nano urea at tillering and jointing stages [19].

4. CONCLUSION

The study demonstrated that applying nano urea to wheat cultivation significantly improves growth parameters, yield attributes, and nitrogen use efficiency. Specifically, using 100% RDN combined with two sprays of Nano Urea resulted in comparable grain yields to traditional urea application, highlighting Nano Urea's potential as an effective alternative to conventional nitrogen fertilizers. The application of 75% RDN with two sprays of Nano Urea achieved the highest NUE, indicating that Nano Urea can enhance nitrogen efficiency while reducing the total amount of nitrogen required. The results suggest that Nano Urea is a promising, eco-friendly solution that can optimize wheat production by improving nutrient uptake, reducing nitrogen losses, and supporting sustainable agricultural practices. Therefore, Nano Urea presents a viable option for enhancing wheat productivity and contributing to more efficient and sustainable farming systems.

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://www.sdiarticle5.com/review-history/123168