

EFFECT OF NANO UREA ON GROWTH, YIELD AND NITROGEN USE EFFICIENCY OF IRRIGATED WHEAT (*Triticum aestivum* L.)

ABSTRACT

In the rabi season of 2021-22, the field study was conducted at Bihar Agricultural University, Bhagalpur (Bihar), to see the effects of nano urea on growth attributes, yield and nitrogen use efficiency of irrigated wheat (*Triticum aestivum* L.). Thirteen treatments with three replications are used in Randomized block design (RBD). 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 (Lamlom, et al., 2023). The biological and biochemical composition of wheat (*Triticum aestivum*) as affected by the bio and organic fertilizers. 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 (Prakash and Kumari., 2024), 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 improved 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. MATERIAL 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: P₂O₅: K₂O.

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 (P₂O₅) ha⁻¹ as SSP and 40 kg potash (K₂O) ha⁻¹ as MOP were fully applied as 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 per meter² 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 (cm²) = $\frac{\text{Total leaf area (cm}^2\text{)}}{\text{ground area (cm}^2\text{)}}$, and Crop growth rate (CGR) reflecting the rate of biomass gain over time, was calculated using the formula: $\text{CGR (gm}^{-2}\text{day}^{-1}\text{)} = \frac{w_2 - w_1}{t_2 - t_1}$. 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 m² 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

$$H.I. = \frac{\text{Economic yield (grain yield) Kg ha}^{-1}}{\text{Biological yield (grain + straw)}} \times 100; \text{ expressed as percentage (\%)}$$

To measure the nutrient (NPK) uptake, plant samples from each treatment were collected and oven dried at 60 ± 5°C 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 $\text{Total (NPK)} = \frac{\text{N+P+K content}}{3}$. For deriving Nitrogen Use Efficiency (NUE- Generally expressed as Kg Kg⁻¹) the formula used was;

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

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 (1959) and Gomez and Gomez (1984).

3. RESULTS AND DISCUSSIONS

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. (2022), Rajasekara et al. (2015), AL-Gym AJK and Al-Asady MHS (2020), and Chandana (2021).

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		Plantheight (cm)	No. of tillersm ⁻²	LAI	CGR
T ₁	RDN+waterspray	92.80	298.67	3.28	0.99
T ₂	RDN+onesprayofnanourea	93.27	302.69	3.41	1.13
T ₃	RDN+twosprayofnanourea	94.64	305.59	3.83	1.03
T ₄	RDN+twosprayofurea (5%)	95.38	318.52	3.87	1.24
T ₅	75%RDN+waterspray	85.12	288.85	2.71	1.86
T ₆	75%RDN+onesprayofnano urea	87.23	279.15	2.85	2.06
T ₇	75%RDN+twosprayofnanourea	88.92	282.90	3.00	3.25
T ₈	75%RDN+twosprayofurea(5%)	89.23	295.58	3.15	2.59
T ₉	50%RDN+waterspray	80.97	220.71	2.37	2.10
T ₁₀	50%RDN+onesprayofnanourea	81.58	232.38	2.44	2.33
T ₁₁	50%RDN+twosprayofnanourea	82.77	253.64	2.50	2.15
T ₁₂	50%RDN+twosprayofurea(5%)	83.32	268.27	2.60	4.94
T ₁₃	Control	76.68	185.59	1.99	4.12
SEm(±)		2.93	12.21	0.24	1.14
CDat5%		8.55	35.63	0.71	NS

The nitrogen level 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. (2020), Choudhary et al. (2020), Mandeewal et al. (2020), and Rahman et al. (2014), who reported that increase in dry matter accumulation was due to higher photosynthetic rates and larger leaf areas.

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

Treatments		Dry matter accumulation (gm ⁻²)				
		25 DAS	50 DAS	75 DAS	100 DAS	At maturity
T ₁	RDN+waterspray	83.66	237.85	375.38	532.01	556.82
T ₂	RDN+onesprayofnanourea	81.34	243.31	380.61	533.33	561.67

T ₃	RDN+twosprayofnanourea	83.55	245.09	387.19	540.96	566.77
T ₄	RDN+twosprayofurea (5%)	79.49	249.01	393.72	555.52	571.19
T ₅	75%RDN+waterspray	78.18	223.64	362.30	481.96	528.45
T ₆	75%RDN+onesprayofnano urea	78.75	230.91	364.89	487.30	538.71
T ₇	75%RDN+twosprayofnanourea	81.88	232.86	370.41	459.10	540.33
T ₈	75%RDN+twosprayofurea(5%)	81.14	242.12	373.63	497.08	561.78
T ₉	50%RDN+waterspray	76.69	190.74	340.38	415.63	468.15
T ₁₀	50%RDN+onesprayofnanourea	78.09	200.04	352.24	425.45	483.76
T ₁₁	50%RDN+twosprayofnanourea	77.92	208.30	357.17	436.96	490.77
T ₁₂	50%RDN+twosprayofurea(5%)	80.09	215.41	358.82	371.93	495.55
T ₁₃	Control	80.22	179.35	292.17	318.77	421.89
SEm(±)		4.35	9.59	17.01	22.44	22.06
CDat5%		NS	28.00	49.64	65.49	64.38

**Twospray: 1stat tillering and 2ndat jointing stage

**Onespray: tillering stage

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 m⁻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.

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 (2013) and Ma et al. (2010). 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 (2020). Test weight improvement is also linked to better water and nutrient absorption facilitated by nano-NPK, leading to enhanced photosynthesis, as observed by Wu (2013).

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

Treatments		Earhead m ²	Grain per ear head ¹	1000-grain weight (g)	Spike length (cm)
T ₁	RDN+waterspray	276.22	48.00	42.40	9.77
T ₂	RDN+onesprayofnanourea	279.18	48.67	43.16	10.16
T ₃	RDN+twosprayofnanourea	282.89	50.00	43.48	10.40

T ₄	RDN+twosprayofurea(5%)	286.05	51.67	43.97	10.83
T ₅	75%RDN+water spray	269.79	43.00	41.75	8.93
T ₆	75%RDN+onesprayofnanourea	272.79	47.00	42.22	9.00
T ₇	75%RDN+twosprayofnanourea	273.63	47.67	42.83	9.34
T ₈	75%RDN +twosprayofurea(5%)	286.73	48.33	42.98	9.40
T ₉	50%RDN+water spray	252.53	46.00	39.68	6.50
T ₁₀	50%RDN+onesprayofnanourea	253.16	46.67	40.22	7.00
T ₁₁	50%RDN+twosprayofnanourea	253.96	46.00	41.12	7.43
T ₁₂	50%RDN +twosprayofurea(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
CDat5%		42.97	6.48	5.24	1.45

**Twospray: 1stat tillering and 2ndat jointing stage

**Onespray: tillering stage

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 lifecycle, and agronomic management practices. Data show that the 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. (2020), Khalil et al. (2019), Ma et al. (2010), and Liu and Liao (2008).

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 (%)
T ₁	RDN+water spray	4210.00	5078.20	9288.20	45.29
T ₂	RDN+onesprayofnanourea	4423.33	5098.32	9521.65	46.40
T ₃	RDN+twosprayofnanourea	4492.33	5235.67	9728.00	46.08
T ₄	RDN+twosprayofurea (5%)	4573.33	5319.33	9892.67	46.25
T ₅	75%RDN+water spray	3927.33	5033.33	8960.67	43.72
T ₆	75%RDN+onesprayofnano urea	4030.00	5142.97	9172.97	43.98
T ₇	75%RDN+twosprayofnanourea	4116.67	5174.97	9291.64	44.29
T ₈	75%RDN+twosprayofurea(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+onesprayofnanourea	3391.67	4494.17	7885.84	43.30

T ₁₁	50%RDN+twosprayofnanourea	3444.33	4533.33	7977.67	43.10
T ₁₂	50%RDN+twosprayofurea(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
CDat5%		433.23	568.79	785.05	NS

**Twospray: 1statilleringand2ndatjointingstage

**Onespray: tilleringstage

3.3 EffectofNanoureaonnitrogenuseefficiency(NUE)

Nano urea, a nanotechnology-based urea formulation, enhances nutrient use efficiency in cropsbyreleasingnitrogenmoreslowlythantraditionalurea.Thiscontrolledreleaseensuresasteady nutrient supply throughout the crop's growth period, improving overall nitrogen availability, especially whenappliedasafoliarspray.Duetotheirsmallsizenanoureparticlesaremoreeasily 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. (2000) supports these findings, emphasizingthatthetimingofnitrogenapplicationiscrucialformaximizingcropuptakeandminimizing losses.Inonestudy,thehighestNUE(10.2kg_{ha}⁻¹)wasobservedinatreatmentcombining75%ofthe recommended nitrogen dose with two foliar sprays of 4% nano urea at tillering and jointing stages.

Table5:TotalNutrientuptakeandNitrogenuseefficiencyasaffectedbynano urea.

Treatments	NutrientUptake				Nitrogen Use Efficiency (KgKg ⁻¹)
	N	P	K	Total (NPK)	
T ₁ RDN+waterspray	104.60	17.28	68.01	63.30	8.50
T ₂ RDN+onesprayofnanourea	117.85	18.22	69.45	68.51	9.80
T ₃ RDN+twospray ofnanourea	121.28	18.50	70.30	70.03	10.10
T ₄ RDN+twosprayofurea(5%)	123.30	18.89	72.41	71.53	9.70
T ₅ 75%RDN+waterspray	97.31	16.29	65.83	59.81	8.80
T ₆ 75%RDN+onespray ofnano urea	109.52	16.53	67.87	64.64	9.60
T ₇ 75%RDN+twosprayofnano urea	111.43	17.06	69.03	65.84	10.20
T ₈ 75%RDN+twosprayofurea(5%)	113.59	17.70	69.95	67.08	9.90
T ₉ 50%RDN+waterspray	79.83	13.26	54.41	49.17	4.20
T ₁₀ 50%RDN+onesprayofnanourea	86.08	14.07	58.20	52.78	5.90
T ₁₁ 50%RDN+twosprayofnanourea	87.40	14.24	59.05	53.56	6.50
T ₁₂ 50%RDN+twosprayofurea(5%)	88.37	14.82	60.01	54.40	5.70
T ₁₃ Control	67.45	11.60	49.42	42.82	-
SEm(±)	3.11	3.11	2.15	4.56	1.32

CDat5%	9.07	9.07	6.28	13.30	3.9
--------	------	------	------	-------	-----

1. 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.

REFERENCE

AL-Gym AJK, Al-Asady MHS. Effect of the method and level of adding NPK nanoparticles and mineral fertilizers on the growth and yield of yellow corn and the content of mineral nutrients of some plant parts. *Plant Archives*. 2020;20(1):38-43.

Bhanuchandar B, Prasanthi M, Dawson J. Effect of level of nitrogen and potassium on growth and yield of rainfed pearl millet (*Pennisetum glaucum* L.). *Int.J.Curr Microbiol Appl Sci*. 2020;9:2194-7.

Chandana P, Latha KR, Chinnamuthu CR, Malarvizhi P, Lakshmanan A. Efficiency of foliar applied nano-nutrients (nitrogen, zinc, and copper) on growth and yield of rice at harvest. *Biol Forum*. 2021;1104-8.

Choudhary V, Sharma PK, Mandeewal RL, Verma BL, Choudhary R. Effect of nitrogen and phosphorus on growth, yield, and quality of coriander (*Coriandrum sativum* L.). *Ann Agric Res (New Series)*. 2020;41:322-4.

Cochran WG, Cox GM. *Experimental Designs*, 2nd Edn, 576. Bombay, India: Asia publishing House. 1985.

Frank M, Husted S. Is India's largest fertilizer manufacturer misleading farmers and society using dubious plant and soil science? *Plant and Soil*. 2024;496(1), 257-267.

Gomez KA, Gomez AA. *Statistical Procedure for Agricultural Research*. International Rice Research Institute, John Wiley and Sons, New York. 1984;139-240.

Khalil MH, Abou-Hadid AF, Abdrabou RT, Al-halim A, AbdEl-Maaboud MS. Response of two maize cultivars (*Zea mays* L.) to organic manure and mineral nano nitrogen fertilizer under Siwa Oasis conditions. *Arab Univ J Agric Sci*. 2019;27(1):299-312.

Kumar Y, Tiwari KN, Nayak RK, Rai A, Singh SP, Singh AN, Raliya R. Nanofertilizers for increasing nutrient use efficiency, yield, and economic returns in important winter season crops of Uttar Pradesh. *Indian J Fert*. 2020;16(8):772-86.

Lamlom SF, Irshad A, Mosa WF. The biological and biochemical composition of wheat (*Triticum aestivum*) as affected by the bio and organic fertilizers. *BMC plant biology*. 2023;23(1), 111.

Liscano JF, Wilson CE, Norman RJ, Slaton NA. Zinc availability to rice from seven granular fertilizers. Fayetteville (CA): Arkansas Agricultural Experiment Station; 2000. Vol. 963.

Liu AX, Liao ZW. Effect of nano-materials on water clusters. *J Anhui Agric Sci*. 2008;36:15780-1.

Ma Y, Kuang L, He X, Bai W, Ding Y, Zhang Z, et al. Effects of rare earth oxide nanoparticles on root elongation of plants. *Chemosphere*. 2010;78(3):273-9.

Mandeewal RL, Soni ML, Gulati J, Shivran H, Choudhary R. Effect of irrigation and nitrogen levels on cluster bean (*Cymopsis tetragonoloba*) in IGNP Stage-II. *Int.J.Curr.Microbiol.App.Sci*;2020. 9(11):

1528-1533

Prakash H, Kumari G. Precision farming: Changing the face of agriculture. In D. K. Patel & S. Dwivedi (Eds.), *Agricultural transformation in the modern era*. 2024; 26-39. Elite Publishing House.

Rahman MZ, Islam MR, Karim MA, Islam MT. Response of wheat to foliar application of urea fertilizer. *J Sylhet Agril Univ*. 2014;1(1):39-43.

Rajasekar M, Nandhini DU, Suganthi S. Supplementation of mineral nutrients through foliar spray - A review. *Int J Curr Microbiol Appl Sci*. 2015;6(3):2504-13.

Sharma SK, Sharma PK, Mandeewal RL, Sharma V, Chaudhary R, Pandey R, et al. Effect of foliar application of nano-urea under different nitrogen levels on growth and nutrient content of pearl millet (*Pennisetum glaucum* L.). *Int J Plant Soil Sci*. 2022;34(20):149-55.

Wu M. Effects of incorporation of nano-carbon into slow-released fertilizer on rice yield and nitrogen loss in surface water of paddy soil. *Adv J Food Sci Technol*. 2013;5:398-403.