E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; SP-7(11): 330-336
Received: 14-08-2024
Accepted: 26-09-2024

Sanjay Kumar Rathour
M.Sc. Scholar, Department of Agronomy, GBPUA&T, Pantnagar, Uttarakhand, India

Amit Bhatnagar
Professor, Department of Agronomy, GBPUA&T, Pantnagar, Uttarakhand, India

Gurvinder Singh
Professor, Department of Agronomy, GBPUA&T, Pantnagar, Uttarakhand, India

Ajay Kumar
Assistance Professor, Department of Agronomy, GBPUA&T, Pantnagar, Uttarakhand, India

Mohammad Hasanain
Scientist, ICAR-IARI, RS Pusa, Samastipur, Bihar, India

Aastika Pandey
ICAR-Indian Agricultural Research Institute, New Delhi, India

Anjali Mehta
ICAR-National Dairy Research Institute, Karnal, Haryana, India

Corresponding Author:
Sanjay Kumar Rathour
M.Sc. Scholar, Department of Agronomy, GBPUA&T, Pantnagar, Uttarakhand, India

Effect of foliar fertilization of nano urea and 2% urea on yield, nutrient uptake, nitrogen use efficiency and economics of maize (*Zea mays* L.)

Sanjay Kumar Rathour, Amit Bhatnagar, Gurvinder Singh, Ajay Kumar, Mohammad Hasanain, Aastika Pandey and Anjali Mehta

DOI: https://doi.org/10.33545/2618060X.2024.v7.i11Se.1992

Abstract
The field experiment was conducted during rainy season of 2022 at experimental farm of NEBCRC, GBPUA&T, Pantnagar (Uttarakhand) in maize (*Zea mays* L.) to assess the effect of nano urea and 2% urea on yield, nutrient uptake, nitrogen use efficiency and economics. The experiment was planned in a randomized block design with 12 treatment combinations each replicated thrice. The experimental results revealed the increase in grain yield, biological yield, nutrient uptake, nitrogen use efficiency and economic benefits by the application of 100% RDN (120 kg N/ha) along with 2 foliar sprays of nano urea or 2% urea at KH and PT stages but it did not vary statistically and remained at par with 5/6th RDN + 2 foliar sprays of nano urea and 100% RDN. The higher grain yield (7,288 kg/ha), biological yield (21,064 kg/ha) were obtained in 100% RDN + 2 foliar sprays of nano urea whereas the maximum total N, P and K uptake by the crop were obtained in 100% RDN + 2 foliar sprays of 2% urea applied at KH and PT stages. Economic parameters did not vary significantly among 100% RDN, 100% RDN + 1 or 2 foliar spray of nano urea, 100% RDN + 2 foliar sprays of 2% urea and 5/6th RDN + 2 foliar sprays of nano urea. However, application of 100% RDN with 2 foliar sprays of nano urea recorded maximum gross and net returns whereas a higher B:C ratio was noted under 100% RDN + 2 foliar sprays of 2% urea. Overall, the 5/6th RDN + 2 foliar sprays of nano urea or 2% urea at the KH and PT stages can be recommended to farmers for enhancing the crop productivity and profitability in maize compared to 100% RDN.

Keywords: Nano urea, nutrient uptake, nitrogen use efficiency, economics, maize

Introduction
It is widely accepted that crop fertilization is an important agricultural practice, as it fulfills crop nutrient demand, optimizes production and economic output. The effective management of fertilizers plays significant role in determining the productivity of various crops including maize. It is acknowledged worldwide that the strategic application of fertilizers is very helpful in enhancing crop yields, thereby ensuring the continuous supply of food and feed. Deficiency of macro (mainly nitrogen) and micronutrients affects the growth and development of plants which may lead to significant decline in crop production and food security worldwide (Upadhyay *et al.*, 2023) [25].

Nitrogen is an essential plant nutrient that is required in large amount by the crop for growth and development. As nitrogen is an essential constituent of chlorophyll, amino acids, nucleic acids, nucleotides, enzymes, hormones, vitamins, alkaloids and phosphatides also, it greatly supports the photosynthesis process (Rathnayaka *et al.*, 2018) [16]. The nutrient use efficiency of commercial fertilizer is low (Parry *et al.*, 2007). In India, it has been reported that the nitrogen use efficiency has declined from 48% during the green revolution to 35% in 2018 (Singh, 2022) [22]. The average nitrogen use efficiency is about 30 to 50% (Juttu *et al.*, 2021) [7]. The remaining nutrients are lost or fixed in the soil and environment and do not reach to the plant system, these phenomena causes various economic loss and environmental degradation (Pachauri *et al.*, 2014) [13]. Growth, productivity and nitrogen use efficiency of the maize crop depends upon the nutrient management system. Nutrient demand of maize is higher as it has high yield potential

compared to the other cereals, particularly nitrogen is required in large amounts and an adequate supply of N is necessary throughout the growing duration for obtaining good yield and economic benefits. In India, cultivation of maize crop is mainly practiced in the rainy season which is accompanied by heavy rainfall and higher relative humidity. Such conditions favour N loss into the soil and environment leads to lesser crop yield, nutrient uptake, N use efficiency and economics (Krasilnikov *et al*., 2022) [8]. To overcome the reduction in yield due to nutrient losses farmers increases the dose of chemical fertilizer (mainly N) which has various harmful impacts on soil health and the environment. Hence, efficient use of nitrogen becomes important for maize production as it increases the yield, economic returns, and minimizes nitrogen losses (Mahmud *et al*., 2022) [11].

Foliar fertilization of nano or conventional fertilizers, especially nano urea can reduce the problems associated with the application of bulk urea in excess (Rathnayaka *et al*., 2018) [16]. As the nano fertilizers have the benefit of controlled release of nutrients, this may allow for the effective duration of nutrient supply to the plant and may reduce adverse environmental impacts. When nano fertilizers are applied as a foliar application, it easily gets absorbed on leaves and enters through stomata, cell wall and other pores of plant cells due to their minute particle size (<50 nm) allowing for high absorption compared to conventional fertilizers (Benzon *et al.*, 2015) [3]. It is reported that foliar application of nano N fertilizers in combination with reduced doses of conventional N fertilizers can enhance the productivity of several cereal crops such as maize, rice, wheat, sorghum, pearl millet and barley. Nano N increases the nutrient uptake and utilization including potassium, phosphorous and results in the increments of overall growth of plant (Leghari *et al*., 2016) [10]. In this view of above, the present study was undertaken to assess the response of foliar fertilization of nano urea on yield, nutrient uptake, N use efficiency and economics of maize.

Methods and Materials

The field trial was conducted at experimental farm Norman E. Borlaug Crop Research Centre of GBPUA&T, located in Pantnagar, Uttarakhand (29.02° N, 79.47° E, 243.83 m MSL). During *Kharif* season 2022 experiment was established. A total of 12 treatments were evaluated in a randomized block design with three replications. The four rates of applied N as [1/3rd, 1/2, 2/3rd, 5/6th and 100% of recommended doses of nitrogen (RDN)] were tested with different combinations of nano-urea and 100% RRN along with foliar spray of 2% urea was also tested to compared with foliar spray of nano urea. The soil of the experimental site was sandy loam in texture, neutral pH (7.5), medium in soil organic carbon (0.68%), low in available nitrogen (234.8 kg N/ha), medium in available phosphorus (18.2 kg P/ha) and available potassium (145.8 kg K/ha) content. The hybrid variety DKC 9144 was sown at a spacing of 60 × 25 cm on 6th July 2022 and harvested on 16 October 2022. The recommended dose of fertilizers (RDF) was 120 kg N, 60 kg P_2O_5 and 40 kg K_2O per hectare. In control, no N fertilizer was applied whereas; P and K were applied as per the recommendation. In the morning hours foliar spray of nano urea @4 ml/l and urea @2% were applied as per the treatments. The spray volume of nano urea was 312.5 l/ha while, the spray volume of 2% urea was 600 l/ha and both were sprayed by using a flat fan nozzle.

Total nutrient (N, P, K) uptake, nitrogen use efficiency and economics of maize are calculated by following formula:

Total Nitrogen Uptake

$$\text{Total nutrient uptake (kg/ha)} = \frac{\text{Nutrient content (\%)} \times \text{yield (kg/ha)}}{100}$$

Nitrogen Use Efficiency

Nitrogen use efficiencies (NUE) such as Partial factor productivity (PFPn), Agronomic efficiency (AEn), Physiological efficiency (PEn) and Apparent recovery efficiency (AREn) was calculated by using the following formula

Partial factor productivity (PFPn) indicates kg grain yield per kg nitrogen applied. It was calculated by using the following formula:

$$\text{Partial factor productivity (PFPn)} = \frac{\text{Yield (kg/ha)}}{\text{Amount of nitrogen applied (kg/ha)}}$$

Agronomic efficiency (AEn) indicates kg grain yield increase per kg N applied. It was calculated by using the following formula:

$$\text{Agronomic efficiency (AEn)} = \frac{\text{Yield}_{\text{fertilized plot}} - \text{Yield}_{\text{control plot}}}{\text{N}_{\text{applied}}}$$

Physiological efficiency (PEn) it indicated kg grain per kg N absorbed and was calculated by using the following formula:

$$\text{Physiological efficiency (PE)} = \frac{\text{Yield}_{\text{fertilized plot}} - \text{Yield}_{\text{control plot}}}{\text{Uptake}_{\text{fertilized plot}} - \text{Uptake}_{\text{control plot}}}$$

Apparent recovery efficiency (REn) indicated% of applied N and was calculated by using the following formula:

$$\text{Apparent recovery efficiency (AREn)} = \frac{\text{Uptake}_{\text{fertilized plot}} - \text{Uptake}_{\text{control plot}}}{\text{N}_{\text{applied}}}$$

Economics

Gross return was computed by converting the economic yield of maize into monetary terms by using the minimum support price of maize grain for the year 2022 (Rs. 19.62/kg) and was expressed as Rs./ha.

Net return was obtained by deducting the cost of cultivation from gross return and was reported as Rs./ha.

The benefit to cost ratio (B:C) was calculated by using the following formula:

$$\text{B:C} = \frac{\text{Net Retrun (Rs./ha)}}{\text{Cost of cultivation (Rs./ha)}}$$

The data recorded during the course of study were analyzed statistically by using the technique of analysis of variance (ANOVA) prescribed for the randomized block design for testing the significance of differences among treatments by 'F test'. A 5% probability level was used for drawing the conclusions.

Results and Discussion

Grain and biological yield

Data obtained in the experiment revealed none of the treatment showed significant superiority to 100% RDN (Table 1). However, the higher grain (7,288 kg/ha) and biological yield (21,064 kg/ha) of maize were recorded under 100% RDN + 2 foliar sprays of nano urea followed by 100% RDN + 2 foliar sprays of 2% urea. Treatments applied with 5/6th and 100% RDN along with foliar spray of nano urea or 2% urea recorded at par grain and biological yields compared to 100% RDN. Treatments with application of 1/3rd, 1/2 and 2/3rd RDN along with 2 foliar sprays of nano urea exhibited significantly lowest grain and biological yields compared with 100% RDN with a percentage grain yield reduction of 38.66%, 25.94% and 14.75%, respectively. The plot under control treatment (0 kg N/ha), irrespective of the nano-fertilizer spray recorded very low grain (2,690 kg/ha) and biological yield (9,501 kg/ha), which was significantly lowest compared to the 100% RDN. Although application of 100% RDN in combination with foliar spray of nano urea or 2% urea recorded more grain and biological yields than 100% RDN but differences were at par. Higher value of yield attributing characters like cob length, cob girth, no. of grain rows/cob, no. of grains /row, no. of grains/cob and 100-grain weight resulted into more grain yield. Biological yield is the sum total of cob yield with husk and stover yield. Therefore, difference in biological yield was due to variation in cob yield with husk and stover yield under respective treatments. These results are in accordance with Ranjan *et al.* (2021) [15] in maize, Rawate *et al.* (2021) [17] in wheat, Samui *et al.* (2022) [21] in maize, Samanta *et al.* (2022) [20] in bajra, Biswas (2022) [18], Choudhary *et al.* (2023) [4] in wheat and Upadhyay *et al.*, (2023) [25] in several crops.

Economics

The data pertaining to economics i.e. cost of cultivation, gross return, net return and B:C ratio as influenced by different treatments were given in Table 1. The additional cost incurred due to the foliar application of nano urea and 2% urea is estimated to be in the range of Rs. 1,630 – Rs. 2,130. The cost of cultivation varied from Rs. 40,096/ha in control treatment to Rs. 44,450/ha in 100% RDN + 2 sprays of nano urea. The differences in cost of cultivation among different treatments were mainly due to differences in amount and price of fertilizer and labor cost incurred on spray. However, the grain yield was slightly higher in the treatments applied with 100% RDN + foliar spray of nano urea or 2% urea than 100% RDN but the differences were at par. Hence in these treatments, higher gross returns and net returns were obtained compared to 100% RDN. However the maximum gross return (1,42,998 Rs./ha) and net return (98,548 Rs./ha) was recorded with the application of 100% RDN + 2 foliar sprays of nano urea at KH and PT stage followed by application of 100% RDN + foliar spray of 2% urea at KH and PT stage but it remained at par with 5/6th RDN + 2 foliar sprays of nano urea and 100% RDN. Application of 100% RDN + foliar sprays of 2% urea at KH and PT stage recorded the maximum B:C ratio (2.27), which was at par with 100% RDN + 2 foliar sprays of nano urea, 100% RDN, 5/6th RDN + 2 sprays of nano urea, 100% RDN + 1 spray of nano urea at KH, 100% RDN + 1 spray of nano urea at PT, 100% RDN + 1 spray of nano urea at KH and 1 spray of 2% urea at PT, 100% RDN + 1 spray of 2% urea at KH and 1 spray of nano urea at PT, over the other treatments. Significantly lowest B:C ratio (0.32) was obtained in control treatment. B:C ratio is obtained by dividing net return by cost of cultivation. Differences in net return and cost of cultivation caused variation in B:C ratio. The increase in net return, gross return and B:C ratio due to foliar spray of nano urea and 2% urea were also reported by Ranjan *et al.* (2021) [15] Attri *et al.* (2022) [2] in rice, Tomar (2022) [2] in maize and Subramani *et al.*, (2023) [23] in Okra.

Effect of nano urea on Total N, P and K uptake

The Total N, P and K uptake as influenced by different treatments were given in Table 2. Maximum total N (135.9 kg/ha), P (47.7 kg/ha) and K (128.5 kg/ha) uptake was observed with the application of 100% RDN + two foliar spray of 2% urea at KH and PT which was at par with 100% RDN + 2 foliar sprays of nano urea at KH and PT, 100% RDN, 5/6th RDN + 2 sprays of nano urea at KH and PT, 100% RDN + 1 spray of nano urea at KH, 100% RDN + 1 spray of nano urea at PT, 100% RDN + 1 spray of nano urea at KH and 1 spray of 2% urea at PT, 100% RDN + 1 spray of 2% urea at KH and 1 spray of nano urea at PT, over the other treatments. Crop fertilized with foliar spray of nano urea or 2% urea along with 100% RDN increased the total N, P and K uptake over 100% RDN but it did not differ statistically. None of the treatments exhibited significantly higher values for total N, P and K uptake than 100% RDN. The significantly lowest total N, P and K uptake was recorded from control treatment. Nutrient uptake by crop solely depends on its nutrient content and dry matter yield. Higher nutrient uptake in treatments with 100% RDN along with a foliar spray of nano urea or 2% urea was due to high nutrient content and dry matter yield under these treatments. Increase in nutrient uptake due to foliar spray of nano urea was also reported by Tomar (2022) [2] in maize, Patidar (2022) [19] in wheat, Upadhyay *et al.*, (2023) [25] in several crops, Kumar *et al.* (2023) [9] in wheat and Attri *et al.*, (2023) [2] in pigeon pea.

Effect of nano urea on nitrogen use efficiency

The nitrogen use efficiency i. e. Partial Factor Productivity (PFPn), Agronomic Efficiency (AEn), Physiological Efficiency (PE), Apparent Recovery Efficiency (APEn) as influenced by different treatments were given in Table 2. Crop grown with the lowest dose of N i.e., 1/3rd RDN (40 kg/ha) + 2 sprays of nano urea recorded significantly highest value of PFPn (104.6 kg grain/kg N applied). PFPn gradually decreased with successive higher levels of N in T4, T5, T6 and T2. Crop raised under 100% RDN did not differ statistically for PFPn of N with crops fertilized with 100% RDN + foliar spray of 2% urea or nano urea. PFPn is directly related to yield and inversely related to amount of applied nutrient hence, the differences in PFPn may be ascribed to differences in grain yield and N dose in different treatments. These results corroborate the findings of Tomar (2022) [2] in maize and Mirji *et al.* (2023) [9] in pigeon pea who also noted higher value of partial factor productivity for N due to foliar spray of nano urea. The variations in AEn, PEn and APEn were due to difference in grain yield obtained and amount of N applied in different treatments. However, the AEn ranged from 34.7 kg grain yield increase/kg N applied in T2 to 39.9 kg grain yield increase/kg N applied in T6, maximum PEn (48.0 kg grain/Kg N absorbed) was recorded in T4 while minimum value (43.9 kg grain/Kg N absorbed) was recorded in T10 while, maximum and minimum APEn (0.86 and 0.75% of applied N, respectively) was obtained in T6 and T3, respectively. Non-significant differences in AEn, PEn and APEn were found among all the treatments. Similar findings were reported by Zhao *et al.* (2005) [26], Tana *et al.* (2015) [24], Kumar *et al.* (2023) [9] in wheat and Subramani *et al.*, (2023) [23] in Okra.

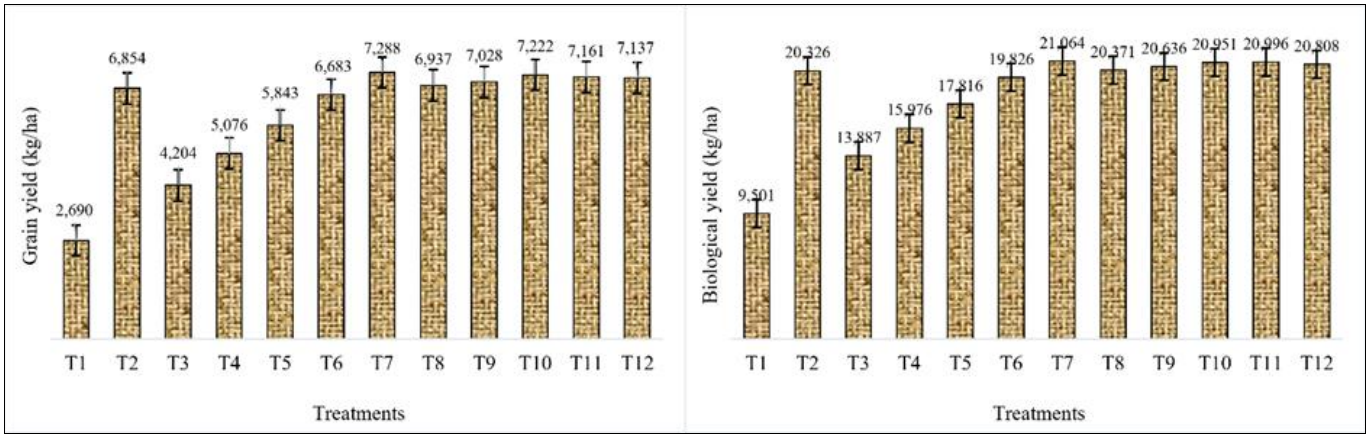


Fig 1: Grain yield and biological yield maize as influenced by different treatments

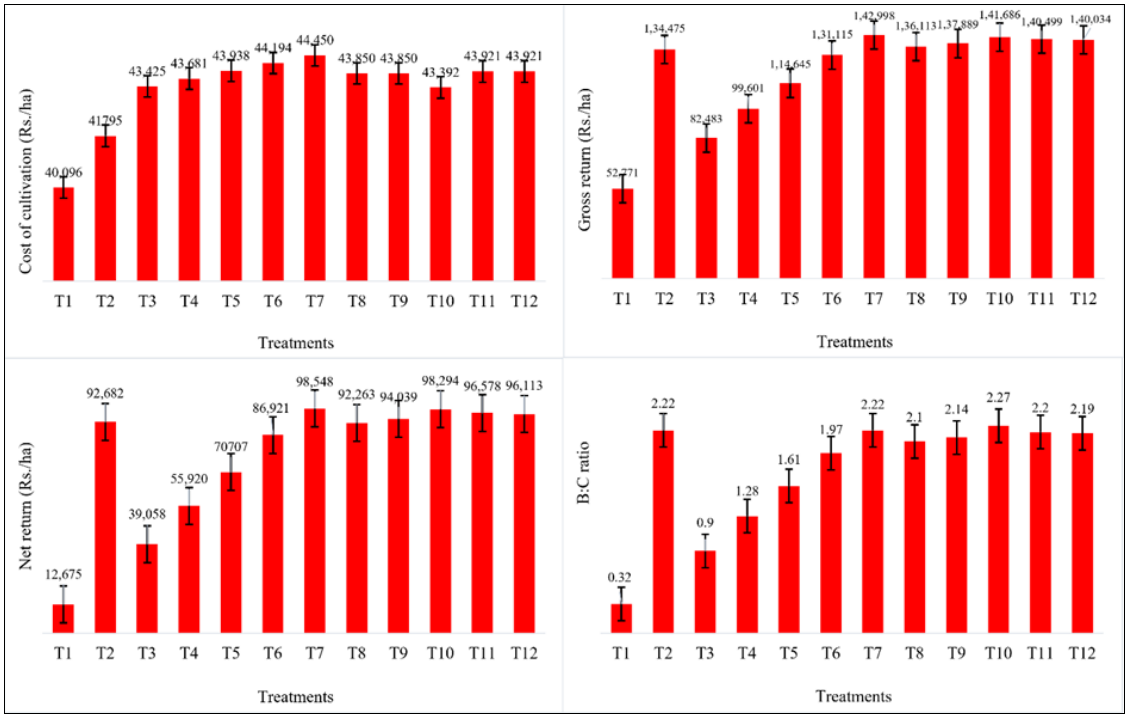


Fig 2: Effect of different treatments on the economics of maize

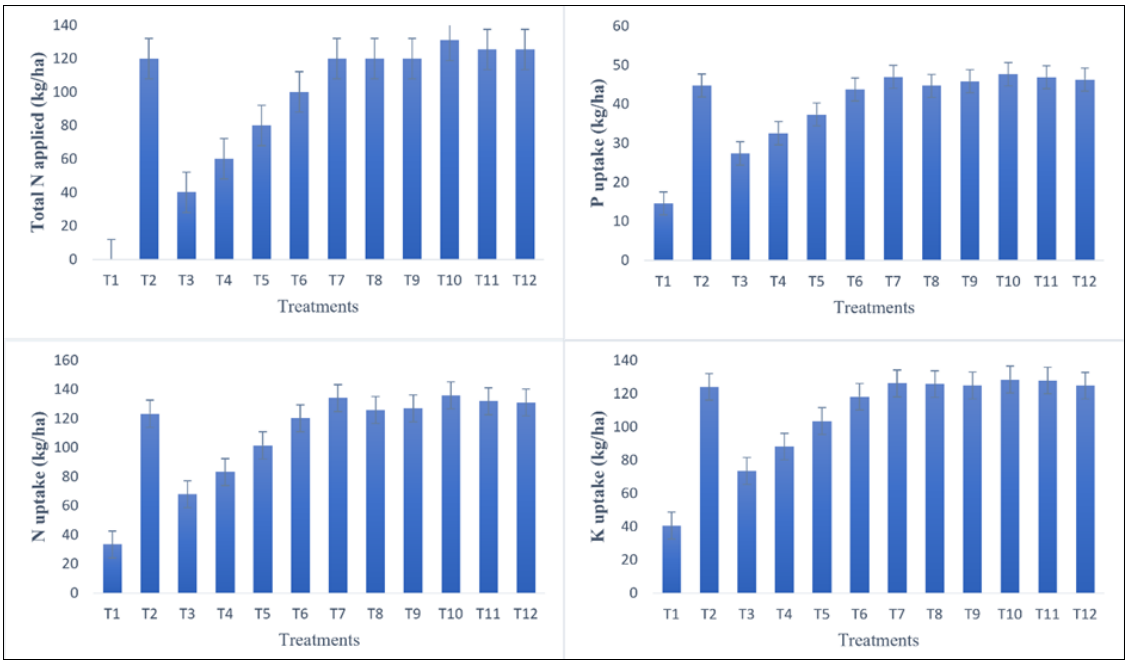
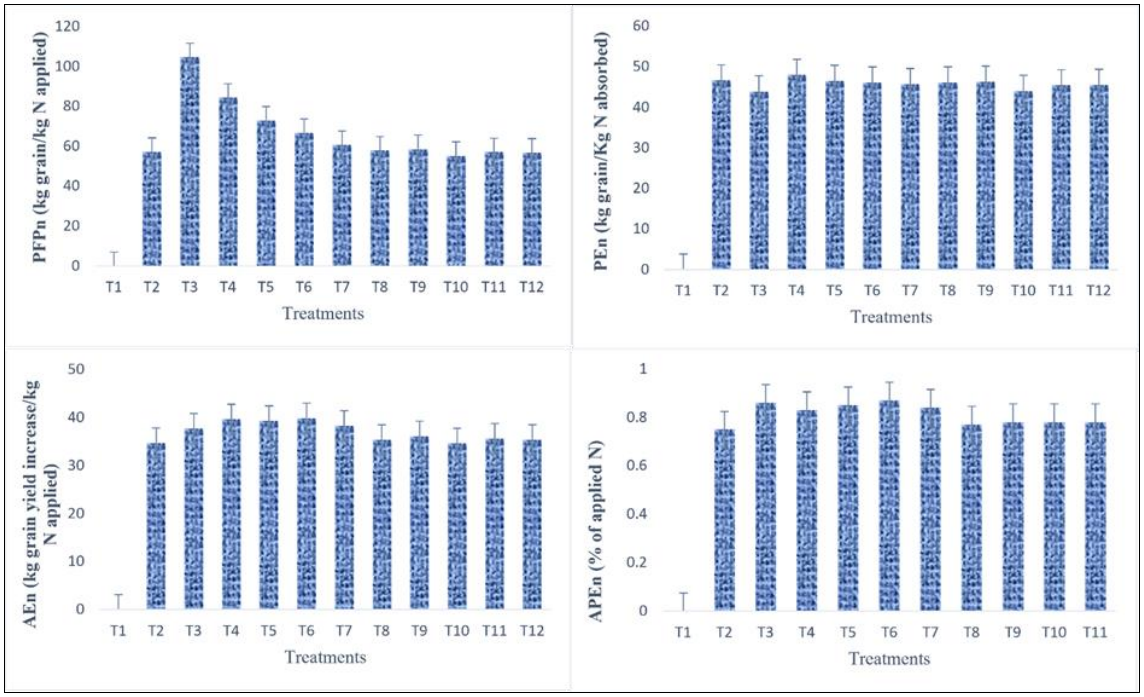


Fig 3: Influence of different treatments on total N, P, K uptake



Note: PFPn = Partial Factor Productivity (kg grain/kg N applied), AEn = Agronomic Efficiency (kg grain yield increase/kg N applied), PEn = Physiological Efficiency (kg grain/Kg N absorbed), APEn = Apparent Recovery Efficiency (% of applied N)

Fig 4: Effect of different treatments on nitrogen use efficiency

Table 1: Grain yield, biological yield, and economics of maize as influenced by different treatments

Treatment	Grain yield (kg/ha)	Biological yield (kg/ha)	Cost of cultivation (Rs./ha)	Gross return (Rs./ha)	Net return (Rs./ha)	B:C ratio
T_1: Control (0 kg N/ha)	2,690	9,501	40,096	52,771	12,675	0.32
T_2: 100% RDN	6,854	20,326	41795	1,34,475	92,682	2.22
T_3: 1/3rd RDN + 2 sprays of nano urea	4,204	13,887	43,425	82,483	39,058	0.90
T_4: 1/2 RDN + 2 sprays of nano urea	5,076	15,976	43,681	99,601	55,920	1.28
T_5: 2/3rd RDN + 2 sprays of nano urea	5,843	17,816	43,938	1,14,645	70707	1.61
T_6: 5/6th RDN + 2 sprays of nano urea	6,683	19,826	44,194	1,31,115	86,921	1.97
T_7: 100% RDN + 2 sprays of nano urea	7,288	21,064	44,450	1,42,998	98,548	2.22
T_8: 100% RDN + 1 spray of nano urea at KH	6,937	20,371	43,850	1,36,113	92,263	2.10
T_9: 100% RDN + 1 spray of nano urea at PT	7,028	20,636	43,850	1,37,889	94,039	2.14
T_{10}: 100% RDN + 2 sprays of 2% urea	7,222	20,951	43,392	1,41,686	98,294	2.27
T_{11}: 100% RDN + 1 spray of nano urea at KH and 1 spray of 2% urea at PT	7,161	20,996	43,921	1,40,499	96,578	2.20
T_{12}: 100% RDN + 1 spray of 2% urea at KH and 1 spray of nano urea at PT	7,137	20,808	43,921	1,40,034	96,113	2.19
S.Em±	279	584	-	5,470	5,470	0.12
CD at 5%	818	1714	-	16,043	16,043	0.37

Table 2: Influence of different treatments on total N, P, K uptake and nitrogen use efficiency

Treatment	Total N applied (kg/ha)	N uptake (kg/ha)	P uptake (kg/ha)	K uptake (kg/ha)	PFPn (kg grain/kg N applied)	AEn (kg grain yield increase/kg N applied)	Pen (kg grain/Kg N absorbed)	APEn (% of applied N)
T_1: Control (0 kg N/ha)	0	33.4	14.6	40.7	-	-	-	-
T_2: 100% RDN	120.0	123.3	44.8	124.1	57.1	34.7	46.6	0.75
T_3: 1/3rd RDN + 2 sprays of nano urea	40.12	68.0	27.4	73.5	104.6	37.7	43.9	0.86
T_4: 1/2 RDN + 2 sprays of nano urea	60.12	83.2	32.6	88.2	84.3	39.6	48.0	0.83
T_5: 2/3rd RDN + 2 sprays of nano urea	80.12	101.5	37.4	103.5	72.9	39.3	46.5	0.85
T_6: 5/6th RDN + 2 sprays of nano urea	100.12	120.2	43.8	118.2	66.7	39.9	46.1	0.87
T_7: 100% RDN + 2 sprays of nano urea	120.12	134.1	47.0	126.2	60.6	38.3	45.7	0.84
T_8: 100% RDN + 1 spray of nano urea at KH	120.06	125.8	44.7	125.8	57.8	35.4	46.1	0.77
T_9: 100% RDN + 1 spray of nano urea at PT	120.06	127.0	45.9	125.0	58.5	36.1	46.3	0.78
T_{10}: 100% RDN + 2 sprays of 2% urea	131.04	135.9	47.7	128.5	55.1	34.6	44.0	0.78
T_{11}: 100% RDN + 1 spray of nano urea at KH and 1 spray of 2% urea at PT	125.58	131.9	46.9	127.9	57.0	35.6	45.4	0.78
T_{12}: 100% RDN + 1 spray of 2% urea at KH and 1	125.58	131.0	46.3	124.8	56.8	35.4	45.5	0.78

spray of nano urea at PT								
S.Em±	-	4.8	1.7	4.5	2.6	2.7	1.4	0.04
CD at 5%	-	14.0	4.9	13.1	7.6	NS	NS	NS

Note: PFPn = Partial Factor Productivity (kg grain/kg N applied), AEn = Agronomic Efficiency (kg grain yield increase/kg N applied), PEn = Physiological Efficiency (kg grain/Kg N absorbed), APEn = Apparent Recovery Efficiency (% of applied N).

Conclusion

Based on the experiment results it can be concluded that foliar application nano urea or 2% urea along with 100% RDN (120 kg N/ha) in maize is helpful in increasing yield, nutrient uptake, nitrogen use efficiency and economic benefits over 100% RDN but the differences were at par. Among the different treatments application of 100% RDN + 2 foliar sprays of nano urea recorded the higher grain yield and biological yield, whereas the higher total N, P and K uptake was obtained with the application of 100% RDN + 2 foliar sprays of 2% urea. Maximum gross return and net return were recorded with the application of 100% RDN + 2 foliar sprays of nano urea but the maximum B:C ratio was obtained in 100% RDN + 2 foliar sprays of 2% urea. Application of 5/6th RDN/ha (100 kg N/ha) + 2 foliar sprays of nano urea at KH and PT stages can save 20 kg N/ha and is economically viable option.

References

1. Tomar A. Augmenting growth and yield performance of maize (*Zea mays* L.) through crop establishment methods and nitrogen management practices. Thesis, Master of Science. Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India; c2022. 83 p.
2. Attri M, Sharma N, Sharma BC. Effect of foliar application of nano urea on productivity and profitability of fine rice under irrigated subtropics of Jammu region. Indian J Ecol. 2022;49(5):1935-1938.
3. Benzon HRL, Rubenecia MRU, Ultra Jr VU, Lee SC. Nano-fertilizer affects the growth, development and chemical properties of rice. Int J Agron Agric Res. 2015;7(1):105-117.
4. Choudhary MS, Intodia SK, Kaushik MK, Saharan V, Singh DP, Lakhawat SS, *et al*. Effect of Nano Urea on Growth indices and Grain Yield of Wheat (*Triticum aestivum* L.) under Southern Rajasthan Conditions. Biol Forum Int J. 2023;15(8):326-331.
5. Dobermann A. Proceedings of the International Fertilizer Industry Association (IFA). In: Nutrient use efficiency–measurement and management: Workshop on Fertilizer Best Management Practices. Brussels: IFA; c2007. p. 1-28.
6. Iqbal MA. Nano fertilizers for sustainable crop production under changing climate: A global perspective. In: Sustainable Crop Production. IntechOpen; c2019. doi: 10.5772/intechopen.89089.
7. Juttu R, Jogula K, Priyadarshini S, Reddy SB, Kumar P, Patra P, *et al*. Strategies and programs for improved nutrient use efficiency, doubling farmer's income and sustainable agriculture: Indian Context. IntechOpen; c2021. doi: 10.5772/intechopen.98267.
8. Krasilnikov P, Taboada MA, Amanullah. Fertilizer use, soil health and agricultural sustainability. Agriculture. 2022;12:462. doi: 10.3390/agriculture12040462.
9. Kumar N, Tripathi SC, Yadav DB. Boosting wheat yield, profitability and NUE with prilled and nano urea in conservation tillage. Nature - Sci Rep. 2023;13:18073. doi: 10.1038/s41598-023-44879-w.
10. Leghari SJ, Wahocho NA, Laghari GM, Hafeezlaghari A, Mustafabhabhan G, Hussaintalpur K, *et al*. Role of nitrogen for plant growth and development: A review. Adv Environ Biol. 2016;10(9):209-219.
11. Mahmud K, Panday D, Mergoum A, Missaoui A. Nitrogen losses and potential mitigation strategies for a sustainable agroecosystem. Sustainability. 2021;13:2400. doi: 10.3390/su13042400.
12. Mirji AC, Seenappa C, Amrutha TG, Matheekur Rehaman HV, Chalapathy V, Shilpa HD. Influence of nano urea on growth, yield and nutrient use efficiency of pigeonpea (*Cajanus cajan* L.) of Karnataka. Biol Forum – Int J. 2023;15(9):403-409.
13. Pachauri RK, Meyer LA, editors. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Core Writing Team. IPCC; Geneva, Switzerland: c2014. p. 151.
14. Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE, editors. Impacts, adaptation and vulnerability, climate change, contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge (UK): Cambridge University Press; c2007. p. 976.
15. Ranjan P, Kumar B, Mala A, Priyadarshi S, Shri A, Babu L, Narayan A, Kumar B. Effect of foliar spray of nano urea on yield and economics of rice. The Pharma Innovation J. 2023;12(1):3030-3033.
16. Rathnayaka RMNN, Mahendran S, Iqbal YB, Rifnas LM. Influence of Urea and Nano-Nitrogen Fertilizers on the Growth and Yield of Rice (*Oryza sativa* L.). Int J Res Publ. 2018;5(2):1-9.
17. Rawate D, Patel JR, Agrawal AP, Agrawal HP, Pandey D, Patel CR, *et al*. Effect of nano urea on productivity of wheat (*Triticum aestivum* L.) under irrigated condition. Pharma Innovation J. 2022;11(9):1279-1282.
18. Biswas R. Nitrogen scheduling in wheat (*Triticum aestivum* L.) through integrated use of nano urea. Thesis, Master of Science. Uttar Banga Krishi Viswavidyalaya, Cooch Behar, West Bengal, India; 2022. 113 p.
19. Patidar R. Effect of nano urea on NUE and productivity of wheat (*Triticum aestivum* L.) under restricted irrigation conditions. Thesis, Master of Science. Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan, India; c2022. p. 115.
20. Samanta S, Maitra S, Tanmoy, Shankar, Gaikwad D, Lalichetti S, *et al*. Comparative performance of foliar application of urea and nano urea on finger millet (*Eleusine coracana* L. Gaertn). Crop Res. 2022;57(3):166-170.
21. Samui S, Lalichetti S, Tanmoy, Shankar, Manohar A, Adhikary R, Maitra S, Praharaj S. Growth and productivity of Rabi maize as influenced by foliar application of urea and nano-urea. Crop Res. 2022;57(3):136-140.
22. Singh B. Nitrogen use efficiency in crop production in India: trends, issues and challenges. Agric Res. 2022;12(7):32-44.
23. Subramani T, Velmurugan A, Bommayasamy N, Swarnam TP, Ramakrishna Y, Jaisankar I, *et al*. Effect of nano urea on growth, yield and nutrient use efficiency of okra under tropical island ecosystem. Int J Agric Sci. 2023;19:134-139.
24. Tana T, Dalga D, Sharma JJ. Effect of weed management

methods and nitrogen fertilizer rates on grain yield and nitrogen use efficiency of bread wheat (*Triticum aestivum* L.) in southern Ethiopia. East Afr J Sci. 2015;9:15-30.
25. Upadhyay PK, Singh VK, Rajanna GA, Dwivedi BS, Dey A, Singh RK, *et al*. Unveiling the combined effect of nano fertilizers and conventional fertilizers on crop productivity, profitability, and soil well-being. Front Sustain Food Syst. 2023;7:1260178. doi: 10.3389/fsufs.2023.1260178.
26. Zhao RF. Fertilization and nitrogen balance in a wheat-maize rotation system in North China. Agron J. 2006;98:938–945.