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Effects of nano urea on Indian mustard (*Brassica juncea*) productivity and nutrient uptake in calcareous soils

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ABSTRACT

The experiment was conducted during winter (*rabi*) seasons of 2021–22 and 2022–23 at ICAR-Directorate of Rapeseed Mustard Research, Bharatpur, Rajasthan to assess the effect of nano urea (NU) spray in conjunction with different rates of soil applied fertilizer (conventional urea) N on growth, yield, nutrient content and uptake of Indian mustard [*Brassica juncea* (L.) Czern. and Coss.] in a calcareous soil of arid and semi-arid region. The experiment was conducted in a randomized complete block design (RCBD) and replicated thrice The treatment combinations consisted of basal applications of fertilizers and foliar spray (FS) of nano urea (NU) either once 30 days after sowing (DAS) or twice 30 and 50–55 DAS. The field experiment comprised of 9 treatments, viz. Control; Recommended dose of fertilizer (RDF); RDN_{25} + NU-1FS; RDN_{25} + NU-2FS; RDN_{50} + NU-1FS; RDN_{50} + NU-2FS; RDN_{100} + NU-1FS; RDN_{75} + NU-1FS; and RDN_{75} + NU-2FS. Results revealed that treatment RDN_{100} + NU-1FS (single sprays of nano urea together with the 100% prescribed dose of N) produced the maximum values of 24.30 and 66.62 q/ha yield of seed and stover, respectively. However, RDN_{75} + NU-2FS produced statistically comparable yield to the treatment RDN_{100} + NU-1FS. By applying nano urea, the recommended N dose can be reduced up to 25% without compromising yield. One FS of NU with RDN_{100} registered highest plant height, main shoot length, main shoot siliquae number, total siliquae number/plant and the number of secondary branches of the plant, and proved superior over other treatments. Further, results exhibited that RDN_{100} + NU-1FS increased N, P, and K uptake values to 66.74, 10.42 and 17.85 kg/ha in seed and 44.23, 9.48 and 78.98 kg/ha in stover. Overall, it has been determined that the most efficient way to increase the yield, concentration, and uptake of N, P, and K in Indian mustard is to apply nano urea foliar at 30 and 60 DAS in conjunction with RDF.

Keywords: Growth, Mustard, Nutrient absorption, Nano urea, Semi-arid, Yield

Indian mustard mustard [*Brassica juncea* (L.) Czern. and Coss.] is sensitive to boron (B), N (N), and sulfur (S) deficiencies, resulting in reduced crop growth, yield, and productivity (Sanwal *et al*. 2016). Moisture-stress regions in India have a huge potential for the cultivation of mustard and Rajasthan is the largest rapeseed-mustard state in the country concerning area (46%) and production (48%). The use of conventional nitrogenous fertilizers has led to a very high losses of N in the environment, leading to eutrophication of water bodies, acidification of soil, and loss of biodiversity (Banger *et al*. 2017). N is the most important nutrient limiting agricultural production in the world. Despite many efforts, nitrogen-use efficiency (NUE) in agriculture is still low, and more than 50% of N applied to agricultural land will be lost to the environment (Mejias *et al*. 2021). Large N losses and low utilization force farmers to increase N- fertilization to increase crop yields (Rathnayaka *et al*. 2018), which increases agricultural costs and affects the environment (Marchiol 2019). Recently, nanotechnology has emerged as a good solution to solve crop nutrient deficiency by increasing the bioavailability of nutrients and limiting losses to the environment. Additionally, they have been shown to prevent the loss of nutrients through direct internalization by plants, thus preventing interaction with soil, water, air, and microorganisms (Panpattee *et al*. 2016). Recently, Indian Farmers Fertilizer Cooperative Limited has developed liquid nano N to improve nutrient utilization and reduce cultivation costs and has developed its product to replace urea to meet the N requirement of crops, especially during the critical growth period. An experiment conducted by Yogendra *et al*. (2020), who conducted experiments on different crops, reported that foliar spraying of nano N alone or in combination with urea during the critical growth period of crops can improve crop yield and nutrient utilization.

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However, there is no information about the site-specific performance of nano N fertilizers in calcareous soil systems in arid and semi-arid regions. Moreover, studies of N content and removal patterns in mustard under a calcareous soil system are the need of hours so that it can be effectively integrated with the package of practices to be followed in the region. Hence, the present sudy was carried out to assess the effect of nano urea (NU) spray in conjunction with different rates of soil applied fertilizer (conventional urea) N on growth, yield, nutrient content and uptake of Indian mustard in a calcareous soil of arid and semi-arid region.

MATERIALS AND METHODS

Site specification and soil characteristics: The experiment was conducted during winter (*rabi*) seasons of 2021–22 and 2022–23 at ICAR-Directorate of Rapeseed Mustard Research, Bharatpur, Rajasthan. The region includes a subtropical and semi-arid climate and is situated in agro-climatic Zone IIIa, which is the semi-arid Eastern Plain. Procedures outlined by Singh *et al*. (2005) were followed in the collection and analysis of the soil samples. Applying Jackson's (1973) methodology, the soil's *p*H and EC were determined. The experimental soil's properties included a clay loam texture, 1.52 Mg/m^3 bulk density, *p*H (1:2.5 ratio), alkaline in reaction (8.5), and 0.46 dS/m electric conductivity of saturation extract (ECe). Low levels of available N (122.71 kg/ha) and extractable P (8.9 kg/ha) from 0.5N $NaHCO_3$ were observed, along with a 0.52% soil organic carbon content. Exchangeable K (1N NH_4OAc) was discovered to have a high range (350 kg/ha).

Treatment details: The experiment was conducted in a randomized complete block design (RCBD) comprises of 9 treatments, viz. Control; Recommended dose of fertilizer (RDF); RDN_{25} + Nano urea (NU)-1 Foliar spray (FS); RDN_{25} + NU-2FS; RDN_{50} + NU-1FS; RDN_{50} + NU-2FS; RDN_{100} + NU-1FS; RDN_{75} + NU-1FS; and RDN_{75} + NU-2FS, replicated thrice. The P and K were applied uniformly to all the treatments as per the recommendation. As a test crop, the mustard variety DRMR IJ-31 was grown using the advised agronomic procedures. Several study parameters were examined, including plant height and primary branches at 45, 90, and harvest stages; girth and secondary branches were measured at 90 and harvest stages, respectively. During the investigation, measurements of the chlorophyll content (45 DAS and 90 DAS) were also made. Following the mustard crop's maturity, yield and yield-related characteristics were assessed.

Nutrient application: The recommended fertilizer doses in terms of N, P_2O_5, and K_2O were 80, 40, and 40 kg/ha, respectively. The fertilizer resources were urea, single super-phosphate, and muriate of potash to supply N, P, and K, respectively. It is recommended to use 50% N-fertilizer (according to the treatment) and 100% phosphorus and potassium fertilizers as base fertilizer for mustard, and the remaining recommended dose of nitrogenous fertilizer as top fertilizer. Spray of NU was made first at 30 DAS and second at 50–55 DAS. The nano urea was applied @4 ml/litre water. Add 4 ml of liquid fertilizer to 1 litre of water, and 500 ml of nanofertilizer to 125 litre of water for one acare land. Apply nano urea foliar spray via a manual knapsack sprayer with a flat fan to cover the leaves. In winter, spray in the evening when there is no dew left on the leaves.

Growth characteristics and yield parameters: When the crop physiologically matures, observe the primary branch, secondary branch, plant height, main shoot length, silica length, number of silica in the main shoot, number of capsules/plant, number of seeds/silica, and test weight of mustard seed were recorded by averaging the values of the five plants in each plot.

Soil and plant analysis

Nutrient content: Once each plot was harvested, including its roots, plant samples were collected in both years and dried in an oven at 70°C until constant weight was achieved. The dried materials were divided into portions and then ground with stainless steel blades. Ground straw and seed samples weighing 1.0 g and 0.5 g, respectively, were digested on a hot plate using mixed diacids (e.g. HNO_3 and $HClO_4$ acids in a 3:1 ratio) (Kumar and Dhaliwal 2021). By following established procedures, the amounts of N, P, K, were determined from an acid extract of seed and stover samples.

Nutrient uptake: The nutrient content was represented as a percentage, and the following formula was used to determine its uptake in kg/ha:

Nutrient uptake by seed/stover (kg/ha) = Nutrient content in seed/stover (%) × Seed/stover yield (q/ha)

Statistical analysis: A three-replication randomized complete block design (RCBD) was used in the trial design. Data were analyzed to determine whether there were significant differences between treatments. Fisher (1950) and Gomez and Gomez (1984) provide a description of the analysis method. The "F" test is used to compare data calculated at the 5% significance level.

RESULTS AND DISCUSSION

Seed and stover yield: Evidence showed that foliar spraying of nano urea affects straw and seed yield of Indian mustard (Table 1). Straw and seed yields of the control reached the lowest level with values of 12.80 and 37.82 q/ha, respectively. But in RDN_{100} + NU-1FS, where, single nano urea sprays were combined with the 100% recommended dose of N, the greatest values of 24.30 and 66.62 q/ha yield of seed and stove were obtained, respectively. This treatment was statistically comparable to treatment RDN_{75} + NU-2FS. Therefore, by using nano urea, the recommended N application can be reduced by 25% without affecting crop yield. RDN_{100} + NU-1FS treatment showed the largest increase in seed and straw yield over to RDF, by 23.66% and 17.53%, respectively. Data relevant to the harvest index as affected by various RDF levels of N and the number of nano urea foliar sprayed are shown in Table 1, with values ranging from 25.28–27.58%. In this study, leaves were sprayed with

Table 1 Effect of foliar application of nano urea on seed and stover yield of Indian mustard during 2021–22 and 2022–23

Treatment	Seed yield (q/ha)			Stover yield (q/ha)			Harvest index (%)
	Year I	Year II	Mean	Year I	Year II	Mean	
Control	12.89	12.71	12.80	40.81	34.82	37.82	25.28
RDF	19.48	19.83	19.65	60.52	52.83	56.68	25.75
RDN_{25} + NU- FS	17.70	16.52	17.12	47.26	42.69	44.98	27.58
RDN_{25} + NU-2FS	19.26	18.02	18.64	51.92	46.27	49.10	27.54
RDN_{50} + NU-1FS	18.81	19.11	18.97	55.56	51.10	53.33	26.23
RDN_{50} + NU-2FS	20.96	20.70	20.83	60.29	56.19	58.24	26.34
RDN_{100} + NU-1FS	25.12	23.47	24.30	68.14	65.09	66.62	26.73
RDN_{75} + NU-1FS	22.41	21.24	21.83	63.19	57.57	60.38	26.55
RDN_{75} + NU-2FS	24.07	22.66	23.37	67.48	61.51	64.50	26.59
SEm±	0.81	0.48	0.37	2.01	1.05	0.99	0.62
CD (*P*=0.05)	2.45	1.46	1.11	6.09	3.18	3.0	NS

RDF, Recommended dose of fertilizer; RDN, Recommended dose of nitrogen; NU, Nano urea; FS, Foliar spray.

nano urea, which is passed directly through stomata and transported through plasmodesmata. When Nanorea enters the plant, it releases N in a controlled manner. Therefore, plants can absorb nano urea 80% more than traditional urea (Kumar *et al*. 2021). Nano urea efficiently releases N and supports photosynthesis by obtaining sufficient amounts of chlorophyll-protein complex to harvest light. Additionally, crops are exposed to less stress, resulting in increased growth and yield (Babu *et al*. 2022). Since N is an important component of chlorophyll, an excess amount of N can have a positive effect on chlorophyll biosynthesis (Sun *et al*. 2020). This may increase photosynthesis and dry matter, which may explain the higher results observed with foliar applied nano urea. Similar findings have been observed by other researchers in the region (Rathore *et al*. 2019), indicating that nano urea application increased the yield of Indian mustard. Crop yield can be increased because nano urea releases N 12 times slower than urea, allowing long-term metabolism (Saurabh *et al*. 2019).

Nano urea has been shown to improve mustard yield and yield characteristics due to the high surface-to-volume ratio of nanoparticles, which promotes rapid nutrient uptake and reduces leaching losses.

Growth and yield characteristics: The growth parameters, like plant height, main shoot length, secondary branches, and chlorophyll content, in Indian mustard at different stages of crop growth and yield (Table 2) attributes, such as the number of siliqua on main shoot and total number of siliqua/plant at harvest (Table 3), were significantly influenced by foliar application of nano urea combined with varying levels of the recommended dose of N fertilization. By increasing the frequency and amount of nano urea leaf spraying, plant height, main branch length, number of main branch silica, total silica/plant, and number of secondary

Table 2 Effect of foliar application of nano urea on growth parameters of Indian mustard during 2021–22 and 2022–23

Treatment	Plant height (cm)			Primary branches			Secondary branches		Chlorophyll (/mg g)	
	45 DAS	90 DAS	At harvest	45 DAS	90 DAS	At harvest	90 DAS	At harvest	30 DAS	60 DAS
Control	68.80	175.57	182.87	4.83	4.90	4.90	10.50	10.07	32.63	36.37
RDF	74.23	183.97	196.50	5.37	5.67	5.67	13.23	13.83	34.00	37.50
RDN_{25} + NU- FS	73.13	178.87	188.90	5.07	5.80	5.70	12.30	11.83	33.10	37.97
RDN_{25} + NU-2FS	74.93	182.20	191.13	5.27	6.30	6.30	14.07	13.23	34.27	38.20
RDN_{50} + NU-1FS	75.90	182.50	192.67	4.97	5.40	5.47	13.70	13.67	35.17	38.47
RDN_{50} + NU-2FS	79.93	184.03	195.50	5.20	5.87	5.90	15.00	15.00	35.52	40.00
RDN_{100} + NU-1FS	81.93	188.57	203.17	5.80	6.20	6.23	16.47	16.13	37.23	39.43
RDN_{75} + NU-1FS	80.27	183.53	194.87	5.40	5.80	6.03	13.33	12.97	36.17	40.70
RDN_{75} + NU-2FS	81.13	185.87	198.40	5.40	6.57	6.53	14.77	14.97	36.50	42.32
SEm±	1.90	6.37	3.50	0.36	0.44	0.48	0.89	0.74	0.48	0.99
CD (*P*=0.05)	5.73	2.11	10.59	NS	NS	NS	2.68	2.23	1.46	2.98

RDF, Recommended dose of fertilizer; RDN, Recommended dose of nitrogen; NU, Nano urea; FS, Foliar spray; DAS, Days after sowing.

Table 3 Effect of foliar application of nano urea on yield attributes of Indian mustard during 2021–22 and 2022–23

Treatment	Siliquae/ plant	Siliquae length (cm)	Seed/ siliquae	Main shoot		Test weight (g)
				Length	No. of siliqua	
Control	251.53	5.49	15.64	69.60	46.00	5.48
RDF	292.33	5.80	16.07	77.47	54.67	5.61
RDN_{25} + NU- FS	261.93	5.67	15.11	73.93	49.07	5.52
RDN_{25} + NU-2FS	274.67	5.70	15.61	77.80	51.53	5.42
RDN_{50} + NU-1FS	284.60	5.62	15.39	77.33	50.93	5.55
RDN_{50} + NU-2FS	293.60	5.94	16.44	79.67	54.33	5.73
RDN_{100} + NU-1FS	373.40	6.16	16.58	85.63	57.57	5.91
RDN_{75} + NU-1FS	355.00	5.78	16.15	79.83	54.07	5.81
RDN_{75} + NU-2FS	361.73	6.29	15.86	84.80	56.43	5.80
SEm±	7.72	0.21	0.33	2.30	1.48	0.14
CD (P=0.05)	23.33	NS	NS	6.97	4.47	NS

RDF, Recommended dose of fertilizer; RDN, Recommended dose of nitrogen; NU, Nano urea; FS, Foliar spray.

branches/plant increased significantly. RDN_{100} + NU-1FS treatment had registered the highest plant height, main shoot length, number of silica in the main shoot, total silica/plant, and second branch of the plant, which is better than other treatments. However, there was no discernible difference in the test weight of mustard seeds, length of the siliqua, number of seeds/siliqua, and primary branches. The reason for the increase in plant height after a single spraying of nano urea and prescribed N fertilizer will be that a large amount of nano N fertilizer stimulates auxin production, thereby promoting cell division and elongation. This has a direct impact on the height and other growth of the plant. The findings are consistent with the results of Al-Gym and Al-Asady (2020).

Improving the use of quality nutrients and N availability can lead to better crop yield and growth, better nutrient content, and overall productivity improvement.These findings are consistent with the study of Raghuvanshi *et al*. (2018). The foliar spraying of nano-fertilizers greatly enhanced the plant development characteristics and production of wheat, according to studies by Al-Juthery *et al*. (2019). Many studies have shown that nano-fertilizers can improve photosynthesis and plant growth (Fatima *et al*. 2020).

Concentration and uptake of nitrogen, phosphorus, and potassium: Fig. 1, shows the two-year (2021–22 and 2022–23) average information on the beneficial effects of mustard harvest on N, P, K concentration and soil organic content. By using the prescribed N fertilizer (RDN_{100} + NU-1FS) together with a nano urea spray, the soil N concentration (147.09 kg/ha) and organic carbon content (3.97 g/kg) at harvest were significantly higher than the control. Inorganic soil fertilization, which involves mineralization and dissolution of available nutrients for plants through direct and indirect nutrient transport mechanisms, may be responsible for increasing soil nutrient availability. However, the application of foliar sprays combined with different levels of N application did not show any significant effects on soil organic carbon content or N content compared to the recommended practice (RDF). Moreover, in treatments involving foliar application with varying levels of the recommended dose of N, the concentrations of P and K in the soil decreased dramatically. These findings indicate that foliar application of nano urea significantly increases the removal of phosphorus and potassium from the soil. According to Ma *et al*. (2009), plants use nanofertilizers, especially nano-NPKs, as biological pumps to improve food and water supply. This suggests that nano urea applied as a foliar spray can also induce a vacuum. Similar findings were reported by Babu *et al*. (2022). It was also observed by Grillo *et al*. (2021). According to Soliman *et al*. (2016) found a positive relationship between phosphorus and N, meaning that when phosphorus is absorbed, the amount of N absorbed also increases.

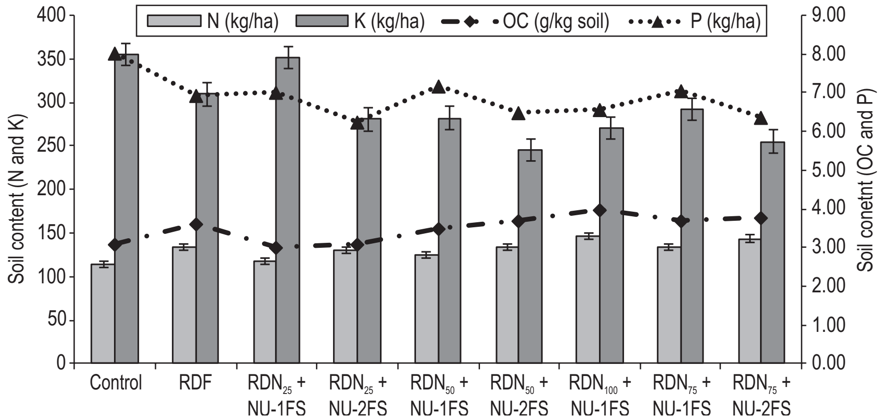

Fig.1 Effect of foliar application of nano urea on nutrient availability in soil after harvesting of crop during 2021–22 and 2022–23.

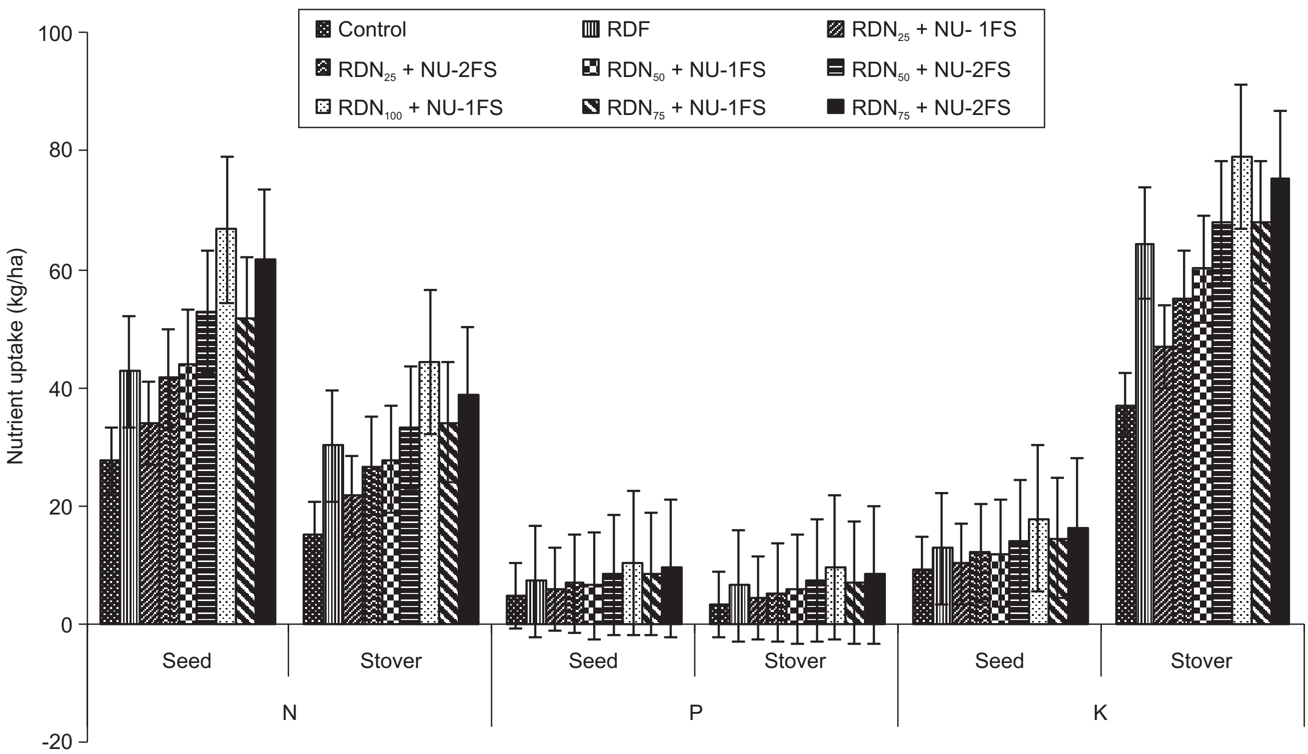

Fig. 2 Effect of foliar application of nano urea on nutrient uptake in seed and stover of Indian mustard during 2021–22 and 2022–23. RDF, Recommended dose of fertilizer; RDN, Recommended dose of nitrogen; NU, Nano urea; FS, Foliar spray.

Data (Supplementary Table 1) shows two-year (2021–22 and 2022–23) average data of N, P, and K concentrations in Indian mustard seeds and straw. All treatments combined with foliar sprays and different recommended N doses resulted in higher N, phosphorus, and potassium content in seeds and straw compared to the control. With one foliar spray of nano urea and 100% of the prescribed dose of N, maximum concentrations of N, phosphorus, and potassium were found in both seed and stover. Treatment RDN_{100} + NU-1FS had the greatest concentrations, with 2.74, 0.43, and 0.74% for the seed and 0.66, 0.14, and 1.19% for the stover, respectively. Treatment RDN_{100} + NU-1FS yielded results comparable to treatment RDN_{75} + NU-2FS in terms of N, P, and K concentrations in seed and stover concentrations.

Research results show that spraying nano urea on the leaves and applying the amount of N fertilizer to the soil affects the uptake of nutrients (Fig. 2). RDN_{100} + NU-1FS treatment, in which mustard leaves were sprayed with nano urea 30 days after planting, showed the highest nutritional value with N, P, and K uptake rates of 66.74 kg/ha, 10.42 kg/ha and 17.85 kg/ha in seed and stover are 44.23 kg/ha, 9.48 kg/ha and 78.98 kg/ha respectively. The results of RDN_{100} + NU-1FS and RDN_{75} + NU-2FS treatments were calculated to statistically comparable with each other regarding N, P, and K uptake of Indian mustard seeds and straw. Seed and straw nutrient absorption and content increase due to the movement of nanoparticles, which increases their transport from the phloem to other parts of the plant (Gonzalez-Melendi *et al*. 2008). According to Kaviani *et al.* (2016) revealed that foliar application of nano-fertilizers significantly increased the N, P, and K content in treated leaves compared to the control. Overall, the use of nano fertilizers has proven to hold significant promise in improving the nutritional quality of food and crop productivity.

The results of this study showed that the application of nano urea in addition to conventional N fertilizers can improve crop yield, quality, and nutrition. The highest seed and straw yields were obtained with the application of RDN_{100}+NU-1FS treatment, 24.30 and 66.62 q/ha, respectively; here we used a nano urea spray combined with 100% of the recommended N fertilizer. The RDN_{100} + NU-1FS treatment produced similar results to the RDN_{75} + NU-2FS treatment, where using two doses of nano urea (1250 ml/ha/spray) with 75% of the recommended N fertilizer (urea). Therefore, using nano urea can reduce the recommended amount of N by up to 25% without affecting yield. In this sense, nano urea is likely to change the way fertilizers are used around the world, including India. However, before this policy can be implemented, the benefits of nano urea need to be further proven in each locality.

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