EFFECT OF NANO-UREA ON PRODUCTIVITY, QUALITY AND ECONOMICS OF FODDER MAIZE (*ZEA MAYS* L.)

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SUMMARY

Maize (*Zea mays* L.) is a vital fodder crop valued for its high biomass yield and nutritional quality, though it's nutrient-exhaustive nature demands effective fertilization strategies. This study evaluated the effects of nano-urea foliar application on the productivity, quality, and economics of fodder maize during the *Kharif* seasons of 2022 and 2023 at the Forage Research Farm, Department of Genetics & Plant Breeding, CCS Haryana Agricultural University, Hisar. The experiment was laid out in a Randomized Complete Block Design (RCBD) with 10 treatments [T_1: Control (without N); T_2:RDF (N:P:K @150:60:40 kg/ha); T_3 : 75 % recommended dose of N + Nano @ 2 ml/litre of water; T_4: 50 % recommended dose of N + Nano @ 2 ml/litre of water; T_5: 75 % recommended dose of N + Nano @4ml/litre of water; T_6: 50 % recommended dose of N + Nano @ 4ml/litre of water; T_7: 75 % recommended dose of N + Nano @ 6ml/litre of water; T_8: 50 % recommended dose of N + Nano @ 6ml/litre of water; T_9:75 % recommended dose of N + Urea (2 % spray), and T_{10}: 50 % recommended dose of N + Urea (2 % spray)] and three replications. Results revealed that 75 % recommended dose of N + Nano @ 6ml/litre of water (T_7) produced the highest plant height (245.6 cm), leaf-to-stem ratio (0.407), green fodder yield (493.9 q/ha), and dry fodder yield (141.3 q/ha), statistically at par with recommended fertilizer dose and 75 % recommended dose of N + Nano @ 4ml/litre of water. Crude protein content (10.93%) and nitrogen uptake (247.1 kg/ha) were also maximized under T_7. Economic analysis indicated that 75% nitrogen with nano-urea at 4 ml/L of water achieved the highest benefit-cost ratio (2.12), followed closely by T_7 (2.10). These findings demonstrate that nano-urea foliar application can effectively substitute 25% of soil-applied nitrogen without compromising fodder yield or quality, offering a sustainable and economically viable approach to nitrogen management in fodder maize production.

Key words: Fodder maize, nano-urea, nitrogen management, crude protein, fodder yield, benefit-cost ratio

Compared to other forage crops, maize produces a substantial amount of biomass in a shorter period and with greater efficiency per unit area. Its wide adaptability, rapid growth, succulence, palatability, and excellent fodder quality make it an ideal choice for livestock feeding. Moreover, maize fodder is free from toxicants, making it safe for animal consumption at any stage of crop growth. However, maize is a nutrient-exhaustive crop, requiring high levels of nutrition for optimal growth and productivity. Therefore, effective nutrient management plays a critical role in achieving high yields. Maize is cultivated in over 166 countries across tropical, subtropical, and temperate regions, covering an estimated global area of 205 million hectares. It contributes to a total production of approximately 1,210 million metric tons, with an average productivity of 5,878 kg/ha. In terms of nutritional composition, maize fodder contains approximately 7.6% crude protein, 2.3% crude fiber, 3.6% crude fat, 63.8% starch, and 1.7% total sugars, with a gross energy value of 3,840 kcal/kg.

Fodder shortages present major challenges to livestock farming, significantly impacting animal nutrition, health, and overall productivity. Addressing this issue requires integrated, sustainable approaches that incorporate climate-resilient practices, effective land and water management, and strategic land use planning. Scientific research underscores the complexity of factors driving fodder scarcity and emphasizes the urgent need to adopt sustainable interventions to ensure long-term fodder security for livestock-dependent communities.

Nano-urea presents multiple agronomic benefits over conventional urea fertilizers. Nano fertilizers are formulated to meet the nutritional requirements of intended crops. The nano form of traditional Agri-inputs allows for the site-specific and regulated release of active substances, reducing excess run-off and preventing eutrophication and residual contamination. Nano particles improve nutrient usage efficiency and reduce environmental protection costs by reducing salt build-up in the soil, as they are needed in less quantity. All of these will lead to an increase in crop nutritional content and seasoning quality (Kannoj *et al*., 2023). Its enhanced solubility and nutrient uptake efficiency promote superior absorption by maize plants, resulting in improved growth, development, and yield outcomes.

MATERIAL AND METHODS

The field experiment was conducted during the *Kharif* season (2022 and 2023) at CCS HAU, Hisar. The soil of the experimental site was sandy loam, with pre-experiment soil properties such as pH (7.7 and 7.8), organic carbon (0.48 and 0.49), available NPK (138.0, 12.45, 246.5 and 144.5, 12.2, 248.6), during 2022 and 2023, respectively. The experiment was laid out in a Randomized Complete Block Design (RCBD) with 10 treatments T_1: Control (without N); T_2: RDF (N:P:K @150:60:40 kg/ha); T_3 : 75 % recommended dose of N + Nano @ 2ml/litre of water ; T_4: 50 % recommended dose of N + Nano @ 2ml/litre of water ; T_5: 75 % recommended dose of N + Nano @ 4ml/ litre of water ; T_6: 50 % recommended dose of N + Nano @ 4ml/litre of water ; T_7: 75 % recommended dose of N + Nano @ 6ml/litre of water ; T_8: 50 % recommended dose of N + Nano @ 6ml/litre of water; T_9: 75 % recommended dose of N + Urea (2 % spray), and T_{10}: 50 % recommended dose of N + Urea (2 % spray)] and three replications. Two foliar sprays of Nano-urea or Urea were applied at 20 and 40 days after sowing (DAS). Spray solution was prepared using 500 liters of water per hectare. The nitrogen component was applied in three equal splits: 50% as basal dose at sowing; 25% at 20 DAS 25% at 40 DAS. Phosphorus (P) and Potassium (K) were applied as per the RDF (60:40 kg/ha) across all treatments receiving nitrogen, using appropriate fertilizers such as Single Super Phosphate (SSP) for phosphorus and Muriate of Potash (MOP) for potassium.

RESULTS AND DISCUSSION

Nitrogen management through conventional fertilizer, urea spray and nano-urea significantly influenced the growth and fodder productivity of maize (Table 1 and 2). Plant population per meter row length

TABLE 1
Effect of nano-urea on yield of fodder maize

Treatment	Green fodder yield (q/ha)			Dry fodder yield (q/ha)			Crude protein yield (q/ha)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1–Control (without N)	301.3	282.2	291.8	83.5	81.1	82.3	6.35	7.06	6.71
T_2–RDF (N:P:K @ 150:60:40 kg/ha)	472.0	455.9	463.9	134.5	130.8	132.6	13.92	15.06	14.49
T_3–75% recommended dose of N+Nano @ 2 ml/litre of water	434.3	415.2	424.8	120.1	117.9	119.0	12.10	13.22	12.66
T_4–50% recommended dose of N+Nano @ 2 ml/litre of water	357.1	336.8	346.9	100.4	97.8	99.10	8.88	9.74	9.31
T_5–75% recommended dose of N+Nano @ 4 ml/litre of water	490.9	486.7	488.8	138.2	141.5	139.9	14.24	16.28	15.26
T_6–50% recommended dose of N+Nano @ 4 ml/litre of water	376.9	358.1	367.5	105.3	103.2	104.3	9.64	10.60	10.12
T_7–75% recommended dose of N+Nano @ 6 ml/litre of water	494.2	493.6	493.9	139.7	142.9	141.3	14.46	16.43	15.45
T_8–50% recommended dose of N+Nano @ 6 ml/litre of water	403.1	383.9	393.5	113.2	111.1	112.2	10.41	11.43	10.92
T_9–75% recommended dose of N+Urea (2% spray)	455.5	432.2	443.9	130.1	120.7	125.4	13.24	13.63	13.44
T_{10}–50% recommended dose of N+Urea (2% spray)	373.0	353.8	363.4	102.3	101.8	102.0	9.10	10.20	9.65
SEm±	14.57	14.2	13.56	4.1	4.1	3.85	0.42	0.46	0.408
CD (p=0.05)	43.61	42.6	40.59	12.4	12.2	11.5	1.25	1.39	1.223

remained statistically unchanged across treatments, indicating uniform crop establishment irrespective of nitrogen source or level. Plant height responded positively to nitrogen application. The maximum plant height *i.e.*, 245.6 cm was observed with 75% recommended nitrogen supplemented with nano-urea at 6 ml/litre of water (T_7), which remained statistically comparable with RDF and T5 (75% RDN combined with nano-urea at 4 ml/litre) (Table 2). Reduced nitrogen levels, irrespective of foliar source, resulted in comparatively shorter plants. In addition to being necessary for the synthesis of several proteins and enzymes, nitrogen availability tends to increase cell size and number, encourage meristematic activity, and enhance protoplasm formation and function, all of which unavoidably support crop growth and development. Since nitrogen is a key component of amino acids, proteins, vitamins, hormones, and enzymes, its significance in plants is evident. These immediately cause cell division, elongation, and increased meristematic activity, which increases internodal length and raises plant height (Xin *et al.*, 2014). Furthermore, even at lower application rates, plant height rose higher when nano fertilizer was mixed with conventional fertilizers (Benzon *et al.*, 2015).

Leaf:stem ratio showed significant variation among treatments and improved with enhanced nitrogen availability. Higher ratio of 0.407 was recorded under treatment T_7 receiving 75% RDN along with nano-urea at 6 ml/litre of water, indicating better leaf development and favorable fodder quality. The lowest leaf:stem ratio was observed in the control, reflecting poor vegetative growth under nitrogen stress (Table 2). Nitrogen is essential for photosynthetic activity and chlorophyll synthesis, both of which support vegetative development. The primary cause is the quick growth of dark green foliage, which absorbs more solar radiation for photosynthesis. The amount and effectiveness of crop-intercepted photosynthetic active radiation mostly determines this rise (Asibi *et al.*, 2019). The increased meristematic activity, and nitrogen also affected cell elongation and division, producing more functioning leaves for a longer amount of time.

Mean basis, green fodder yield was markedly influenced by nitrogen treatments. The highest green fodder yield (493.9 kg/ha) was produced under 75% RDN supplemented with nano-urea at 6 ml/litre of water (T_7), closely followed by treatment T_5 (75% RDN with nano-urea at ml/litre of water) and RDF (Table 1). These treatments remained statistically at par, suggesting that partial substitution of soil-applied nitrogen with nano-urea effectively sustained biomass production. Dry fodder yield followed a trend similar to green fodder yield. Maximum dry matter accumulation (141.3 kg/ha) was recorded with 75% RDN combined with nano-urea at 6 ml/litre of water (T_7), which remained comparable with RDF and treatment T_5 (Table 1). The lowest dry fodder yield was observed in the absence of nitrogen application. This is primarily because nitrogen is essential for many metabolic processes in plants, including cell division and expansion, enzymatic activity, photosynthetic efficiency, and meristematic activity. These processes improved vegetative growth, as shown by increased plant height and leaf stem ratio, which in turn increased the production of green biomass. The findings of Kumar *et al.* (2024);

TABLE 2

Response of fodder maize to nano-urea

Treatment	Plant stand/ mrl	Plant height (cm)	L:S ratio	Crude protein (%)	N content (%)	N Uptake (kg/ha)
T_1–Control (without N)	9.72	194.1	0.337	8.16	1.31	107.3
T_2–RDF (N:P:K @ 150:60:40 kg/ha)	9.89	242.1	0.402	10.93	1.75	231.9
T_3–75% recommended dose of N+Nano @ 2 ml/litre of water	9.89	230.8	0.37	10.65	1.70	202.5
T_4–50% recommended dose of N+Nano @ 2 ml/litre of water	9.55	224.1	0.343	9.40	1.50	149.0
T_5–75% recommended dose of N+Nano @ 4 ml/litre of water	9.44	243.8	0.400	10.90	1.75	244.2
T_6–50% recommended dose of N+Nano @ 4 ml/litre of water	9.55	227.7	0.361	9.72	1.56	162.0
T_7–75% recommended dose of N+Nano @ 6 ml/litre of water	9.78	245.6	0.407	10.93	1.75	247.1
T_8–50% recommended dose of N+Nano @ 6 ml/litre of water	9.89	228.4	0.368	9.74	1.56	174.7
T_9–75% recommended dose of N+Urea (2% spray)	9.89	235.2	0.373	10.74	1.72	215.0
T_{10}–50% recommended dose of N+Urea (2% spray)	9.78	229.1	0.336	9.46	1.51	154.4
SEm±	0.42	3.36	0.01	0.153	0.025	6.529
CD (p=0.05)	NS	10.07	0.03	0.459	0.073	19.548

Shekara and Chikkarugi (2025); Geervani *et al*. (2025) confirmed the same results.

Crude protein concentration as well as crude protein yield of fodder maize improved distinctly with the application of nitrogen (Table 2 and 1). Treatments receiving the recommended dose of fertilizers (T_2) and 75% of recommended nitrogen supplemented with nano-urea at 6 ml/litre of water (T_7) recorded the highest crude protein content *i.e*., 10.93% and 10.93%, respectively and these were comparable with 75 % recommended dose of N + Nano @ 2ml/litre of water (T_3), 75 % recommended dose of N + Nano @ 4ml/ litre (T_5) and 75 % recommended dose of N + Urea (2 % spray) (T_9) (Table 2). A consistent reduction in crude protein content was observed under 50% nitrogen levels irrespective of the source, while the lowest values were noted in the control. Crude protein yield (Table 1) followed a similar pattern and was largely governed by fodder biomass production, with the maximum yield (15.45 q/ha) obtained under 75% RDN supplemented with nano-urea at 6 ml/litre of water (T_7), which remained at par with 75% RDN + nano-urea at 4 ml/litre of water (T_5) and RDF (T_2). Sub-optimal nitrogen supply resulted in a marked decline in protein yield, and the control treatment recorded the minimum crude protein yield due to restricted biomass production and lower protein accumulation. The increase in protein percentage might be attributed to improved vegetative development and grain production as a result of spraying a high amount of nutrients in nano-fertilizer. This may be attributed to more surface area and more availability of nutrients to the crop plant which boost quality parameters of the plant (such as protein, and sugar content) by speeding up the rate of reaction or synthesis process within the plant system. Nano fertilizers have a large surface area and particle size smaller than the pore size of plant leaves, allowing for greater penetration into plant tissues from the applied surface and improved absorption and nutrient usage efficiency. Similar results were obtained by Burhan and AL-Hassan (2019); Hasan and Saad (2020); Kannoj *et al.* (2022b).

Nitrogen concentration in fodder maize and total nitrogen uptake varied appreciably with the mode and level of nitrogen application (Table 2). Plots supplied with the recommended fertilizer dose (T_2) and those receiving 75% of the recommended nitrogen along with nano-urea at 4 and 6 ml/litre of water (T_5 and T_7) consistently recorded higher nitrogen content *i.e.*, 1.75%, suggesting better assimilation and retention of nitrogen in plant tissues. In contrast, treatments receiving only 50% nitrogen, irrespective of the source, showed comparatively lower nitrogen concentration, while the minimum was observed under the control. Total nitrogen uptake followed the similar pattern to dry fodder yield, with the highest uptake (247.1 kg/ ha) recorded under 75% RDN supplemented with nano-urea at 6 ml/litre of water (T_7) closely followed by 75% RDN + nano-urea at 4 ml/litre of water (T_5) 244.2 kg/ha and RDF (T_2) 231.9 kg/ha, all of which remained statistically comparable. A marked reduction in nitrogen uptake was noted under reduced nitrogen levels, and the control treatment registered the lowest uptake due to poor biomass accumulation and limited nitrogen availability. Nano fertilizers have large surface area and particle size smaller than the pore size of plant leaves, allowing for greater penetration into plant tissues from the applied surface and improved

TABLE 3
Effect of nano-urea on economics of fodder maize

Treatment	Cost of cultivation (Rs./ha)	Gross returns (Rs./ha)	Net Returns (Rs./ha)	BC ratio
T_1–Control (without N)	45413	58,353	12,940	1.29
T_2–RDF (N:P:K @ 150:60:40 kg/ha)	45032	92,789	47,757	2.06
T_3–75% recommended dose of N+Nano @ 2 ml/litre of water	45323	84,953	39,629	1.88
T_4–50% recommended dose of N+Nano @ 2 ml/litre of water	43668	69,389	25,721	1.59
T_5–75% recommended dose of N+Nano @ 4 ml/litre of water	46243	97,766	51,523	2.12
T_6–50% recommended dose of N+Nano @ 4 ml/litre of water	44588	73,500	28,912	1.65
T_7–75% recommended dose of N+Nano @ 6 ml/litre of water	47164	98,778	51,614	2.10
T_8–50% recommended dose of N+Nano @ 6 ml/litre of water	45508	78,700	33,192	1.73
T_9–75% recommended dose of N+Urea (2% spray)	44526	88,775	44,249	2.00
T_{10}–50% recommended dose of N+Urea (2% spray)	42870	72,678	29,808	1.70
SEm±		2,712	2,712	0.06
CD (p=0.05)		8,120	8,120	0.18

absorption and nutrient use efficiency. This aid in the rapid and simple absorption of nutrients by leaves (Dimkpa *et al*., 2015; Qureshi *et al*., 2018; Kannoj *et al*., 2023). These results are in correlation with results of Mahil and Kumar (2019); Hasan and Saad (2020) Kannoj *et al*. (2022a).

Gross returns, net returns and benefit–cost ratio of fodder maize differed distinctly with the level and source of nitrogen application and were largely governed by fodder yield performance. The highest gross (98,778 Rs./ha) and net returns (51,614 Rs./ ha) were realized under the treatment (T_7) 75% of the recommended nitrogen supplemented with nano-urea at 6 ml/litre of water and these were closely followed by 75% RDN combined with nano-urea at 4 ml/litre of water and the recommended fertilizer dose, indicating superior economic performance of these treatments despite slightly higher cultivation costs (Table 3). Treatments receiving only 50% nitrogen, irrespective of whether supplied through nano-urea or urea spray, recorded comparatively lower returns, while the control treatment registered the minimum returns due to poor fodder production. However, maximum B: C (2.12) was fetched with the application of 75 % recommended dose of N + Nano @ 4 ml/litre of water (T_5) followed by 75 % recommended dose of N + Nano @ 6 ml/litre of water (T_7) and RDF, whereas reduced nitrogen levels and the control resulted in lower ratios, indicating limited economic advantage under sub-optimal nitrogen supply.

CONCLUSION

Based on the results, it can be concluded that the application of 75% recommended dose of nitrogen (RDN) combined with nano-urea at 6 ml/litre significantly enhanced green fodder and crude protein and was statistically at par with 75% RDN + nano-urea @ 4 ml/litre and the recommended dose of fertilizers (RDF). The application of nano-urea, particularly @ 4 to 6 ml/litre of water along with 75% RDN, can effectively replace the application of 100% nitrogen dose through conventional urea to improve fodder yield and quality in maize cultivation.

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