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Role of nano-urea in enhancing growth and productivity of hybrid maize *(Zea mays L.)*

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Abstract
A field experiment was conducted during the *kharif* season of 2024 at the Agricultural Research Farm, Vivekananda Global University, Jaipur, Rajasthan, to assess the role of nano-urea in improving growth, productivity, nutrient-use efficiency, and economics of hybrid maize *(Zea mays L.)* variety SMH-5. The study employed a randomized complete block design with 10 treatments, including control and combinations of recommended dose of nitrogen (RDN, 120 kg/ha as prilled urea) with foliar sprays of nano-urea at varying rates and timings. Results indicated that the treatment with 50% RDN as basal + 2 sprays of nano-urea @ 4 ml L^{-1} (at 30 and 60 days after sowing, DAS) significantly enhanced plant population (up to 32.38% increase at 30 DAS), plant height (up to 31.23% at harvest), dry matter accumulation (up to 33.01% at harvest), yield attributes (e.g., 57.85% more grains/cob), grain yield (87.85% increase to 74.84 q/ha), nutrient-use efficiencies (highest agronomic efficiency of 154.3 kg grain/kg N), and economic returns (net return of ₹105,204.6/ha, B:C ratio 1.81). This approach reduced nitrogen losses, improved soil nutrient status, and promoted sustainable maize production under semi-arid conditions.

Keywords: Hybrid maize, nano-urea, nitrogen-use efficiency, growth, yield, economics

1. Introduction

Maize *(Zea mays L.)*, known as the "queen of cereals," is a versatile crop with wide adaptability, serving as a staple food, animal feed, and industrial raw material. In India, it ranks third after rice and wheat, covering 9.7 million ha with a production of 31 million tons and productivity of 3.19 t/ha (Anonymous, 2020b) [5]. Globally, production reaches 1147.7 million tons from 193.7 million ha (Anonymous, 2020a) [4]. Maize demands high nitrogen (N) for growth, but conventional urea application leads to losses via leaching, volatilization, and runoff, with recovery rarely exceeding 50% (Conant *et al*., 2013) [7]. Overuse skews NPK ratios, increases pest susceptibility, and causes lodging (Dahiya *et al*., 2018) [8].

Nano-urea, a nanotechnology-based liquid fertilizer with 4% N (w/v) in 20–50 nm particles, offers higher efficiency (>80%) through foliar uptake via stomata and phloem translocation (Kumar *et al*., 2020a; Wang *et al*., 2013) [10, 19]. It minimizes environmental losses and stores unused N in plant vacuoles for gradual release (Kumar *et al*., 2020b) [11]. This study aimed to: (1) evaluate nano-urea's impact on maize growth and yield; (2) assess nutrient-use efficiency and quality; and (3) analyze economic viability.

3. Materials and Methods

3.1 Experimental Site

The experiment was carried out during the kharif season of 2024 at the Agricultural Research Farm, Vivekananda Global University, Jaipur, Rajasthan (Agro-climatic zone III A, semi-arid Eastern Plain Zone). The region features a semi-arid climate with summer highs of 48 °C, winter lows of 1 °C, and annual rainfall of 450–550 mm, mainly in July–August. During the crop period, maximum temperatures ranged from 30.2 °C to 40.9 °C, minimum from 14.3 °C to 25.4 °C, relative humidity 15–85%, and sunshine hours 1.8–9.3. Soil was loamy sand, alkaline (pH 8.2), low in organic carbon (0.32%), available N (185 kg/ha), and P (12.5 kg/ha), and medium in K (245 kg/ha).

3.2 Variety and Cropping History

The hybrid maize variety Shalimar Maize Hybrid-5 (SMH-5), a medium-duration (90–100 days) cultivar with high yield potential (80 q/ha) and tolerance to diseases, was used. The field had mung bean and fallow in 2023–24, followed by maize in kharif 2024.

3.3 Treatments and Design

Ten treatments were arranged in a randomized complete block design with three replications (30 plots): T_1 (Control), T2 (RDN as basal prilled urea @ 120 kg/ha), T_3 (75% RDN basal + 1 spray nano-urea @ 2 ml L^{-1} at 45 DAS), T4 (75% RDN basal + 1 spray @ 4 ml L^{-1} at 45 DAS), T_5 (50% RDN basal + 2 sprays @ 2 ml L^{-1} at 25 & 45 DAS), T_6 (50% RDN basal + 2 sprays @4 ml L^{-1} at 25 & 45 DAS), T7 (25% RDN basal + 2 sprays @6 ml L^{-1} at 25 & 45 DAS), T_8 (25% RDN basal + 2 sprays @8 ml L^{-1} at 25 & 45 DAS), T9 (25% RDN basal + 1 spray @ 6 ml L^{-1} at 45 DAS), $T_1$0 (25% RDN basal + 1 spray @ 8 ml L^{-1} at 45 DAS). Uniform basal doses of 50 kg P_2O_5/ha and 40 kg K_2O/ha were applied via DAP and MOP. Plot size was 4.2 m × 6 m (25.2 m²), with planting density of 30 cm × 60 cm.

Table 1: Treatments and their symbols

S. No	Treatments	Symbol
1	Control	T_1
2	Recommended dose of Nitrogen (RDN) as basal (prilled urea) @120 kg ha^{-1}	T_2
3	75% RDN as basal + 1 spray nano-urea @ 2 ml L^{-1} (45 DAS)	T_3
4	75% RDN as basal + 1 spray nano-urea @ 4 ml L^{-1} (45 DAS)	T_4
5	50% RDN as basal + 2 sprays nano-urea @ 2 ml L^{-1}(25 and 45 DAS)	T_5
6	50% RDN as basal + 2 sprays nano-urea @ 4 ml L-1 (25 and 45 DAS)	T_6
7	25% RDN as basal + 2 sprays nano-urea @ 6 ml L-1 (25 and 45 DAS)	T_7
8	25% RDN as basal + 2 sprays nano-urea @ 8 ml L^{-1} (25 and 45 DAS)	T_8
9	25% RDN as basal + 1 spray nano-urea @ 6 ml L^{-1} (45 DAS)	T_9
10	25% RDN as basal + 1 spray nano-urea @ 8 ml L-1 (45 DAS)	T_{10}
RDF = Recommended dose of fertilizer (120 kg N +50 kg P_2O_5/ha+ 60 kg K_2O)		

3.4 Cultural Practices

The field was prepared with two tractor ploughings, harrowing, and planking for fine tilth. Seeds (25 kg/ha) were treated with Bavistin + Captan (2 g/kg) and Metalaxyl (4 g/kg), sown at 60 cm × 20 cm. Thinning was done at 15 DAS. Irrigation was via check basin during critical stages. Weeds were controlled manually at 15–20 DAS and with Tembotrione (150 g a.i./ha) at 30 DAS. Pests were managed with Chlorpyriphos (0.05%). Harvesting was manual, with grain yield adjusted to 15% moisture.

3.5 Observations

Growth: Plant population (plants/m row at 30 DAS and harvest), height (cm at 30, 60, 90 DAS, harvest), dry matter (q/ha at 30, 60, 90 DAS, harvest), phenological stages (days to knee-high, tasseling, silking, maturity). Yield attributes: Cobs/plant, rows/cob, grains/cob, seed index (g), cob length/diameter (cm with/without husk), grain/ stover/biological yield (q/ha), harvest index (%). Nutrient analysis: N (Kjeldahl), P, K content/uptake in grain/stover; protein (%) = N × 6.25. Efficiencies: Agronomic (kg grain/kg N), physiological (kg grain/kg N uptake), apparent recovery (%), partial factor productivity (kg grain/kg N applied). Economics: Gross/net returns, B:C ratio based on market prices.

3.6 Statistical Analysis

Data were subjected to ANOVA, with significance at $p \leq 0.05$.

4. Results and Discussion

4.1 Growth Parameters

Plant population at 30 DAS ranged from 4.55 (T9) to 6.95 plants/m row (T_5, 32.38% increase over control), and at harvest from 4.45 to 6.85 (T_5, 33.01%). T_6 showed consistent performance (19.05–19.42% increase). Nano-urea's efficient N delivery enhanced seedling vigor (Rathnayaka *et al.*, 2018) [12].

Table 2: Impact of different treatments of nano-urea on plant population of maize hybrid (SMH-5)

S. No.	Treatments	Plant population per meter row length	
		30 DAS	Harvest
1	Control	5.25	5.15
2	Recommended dose of Nitrogen (RDN) as basal (prilled urea) @120 kg ha-1	5.35	5.25
3	75% RDN as basal + 1 spray nano-urea @ 2 ml L-1 (45 DAS)	5.44	5.34
4	75% RDN as basal + 1 spray nano-urea @ 4 ml L-1 (45 DAS)	5.49	5.39
5	50% RDN as basal + 2 sprays nano-urea @ 2 ml L-1 (25 and 45 DAS)	6.95	6.85
6	50% RDN as basal + 2 sprays nano-urea @ 4 ml L-1 (25 and 45 DAS)	6.25	6.15
7	25% RDN as basal + 2 sprays nano-urea @ 6 ml L-1 (25 and 45 DAS)	4.75	4.65
8	25% RDN as basal + 2 sprays nano-urea @ 8 ml L-1 (25 and 45 DAS)	4.85	4.75
9	25% RDN as basal + 1 spray nano-urea @ 6 ml L-1 (45 DAS)	4.55	4.45
10	25% RDN as basal + 1 spray nano-urea @ 8 ml L-1 (45 DAS)	4.66	4.56
	CD ($p \leq 0.05$)	0.237	0.248
	SEm ±	0.079	0.083
	CV (%)	2.566	2.736

Plant height increased significantly under T_6 (up to 31.23% at harvest), due to N's role in cell division and photosynthesis (Ren *et al.*, 2021) [14]. Dry matter accumulation peaked in T_5/T_6 (up to 33.01% at harvest), reflecting improved assimilate production (Reddy *et al.*, 2022). Phenological stages were delayed under T_6 (e.g., 10.74% to maturity), extending vegetative growth (El-Ghobashi and Ismail, 2022) [9].

Table 3: Impact of different treatments of nano-urea on plant height at different growth stages of maize hybrid (SMH-5).

S. No.	Treatments	Plant height (cm)			
		30 DAS	60 DAS	90 DAS	Harvest
1	Control	21.89	79.74	124.48	129.24
2	Recommended dose of Nitrogen (RDN) as basal (prilled urea) @120 kg/ha	32.65	113.01	181.24	190.51
3	75% RDN as basal + 1 spray nano-urea @ 2 ml/L (45 DAS)	33.79	113.87	182.03	188.98
4	75% RDN as basal + 1 spray nano-urea @ 4 ml /L (45 DAS)	33.44	114.07	185.74	191.67
5	50% RDN as basal + 2 sprays nano-urea @ 2 ml /L (25 and 45 DAS)	32.62	115.17	189.47	195.01
6	50% RDN as basal + 2 sprays nano-urea @ 4 ml /L (25 and 45 DAS)	32.89	120.71	197.07	201.96
7	25% RDN as basal + 2 sprays nano-urea @ 6 ml /L (25 and 45 DAS)	27.65	105.61	172.11	180.45
8	25% RDN as basal + 2 sprays nano-urea @ 8 ml /L (25 and 45 DAS)	27.35	106.17	173	180.58
9	25% RDN as basal + 1 spray nano-urea @ 6 ml /L (45 DAS)	27.05	92.67	156.24	160.74
10	25% RDN as basal + 1 spray nano-urea @ 8 ml /L (45 DAS)	27.22	92.84	156.88	161.21
	CD ($p \leq 0.05$)	1.51	4.254	8.199	8.415
	SEm ±	0.504	1.421	2.738	2.811
	CV (%)	2.945	2.335	2.76	2.734

4.2 Yield Attributes and Yield

T_6 recorded highest rows/cob (14.69, 20.31%), grains/cob (34.68, 57.85%), cob length (22.62 cm with husk, 15.76%), but non-significant changes in cobs/plant and seed index. Grain yield reached 74.84 q/ha (87.85% over control), stover 176.83 q/ha (67.14%), biological 251.67 q/ha (67.12%), and harvest index 42.32% (12.35%). These gains attribute to better N translocation and pollen viability (Sahu *et al.*, 2022; Saitheja *et al.*, 2022) [15, 16].

Table 4: Impact of different treatments of nano-urea on yield of maize hybrid (SMH-5).

S. No.	Treatments	Seed Yield (kg/ha.)	Stover yield (kg/ha.)	Biological yield (kg/ha.)	Harvest Index
1	Control	38.83	63.94	102.77	37.78
2	Recommended dose of Nitrogen (RDN) as basal (prilled urea) @120 kg/ha	62.31	93.58	155.89	39.97
3	75% RDN as basal + 1 spray nano-urea @ 2 ml/L (45 DAS)	64.77	96.39	161.16	40.18
4	75% RDN as basal + 1 spray nano-urea @ 4 ml /L (45 DAS)	67.16	97.9	165.06	40.68
5	50% RDN as basal + 2 sprays nano-urea @ 2 ml /L (25 and 45 DAS)	69.95	99.27	169.22	41.33
6	50% RDN as basal + 2 sprays nano-urea @ 4 ml /L (25 and 45 DAS)	73.83	99.98	173.81	42.47
7	25% RDN as basal + 2 sprays nano-urea @ 6 ml /L (25 and 45 DAS)	61.48	93.27	154.75	39.72
8	25% RDN as basal + 2 sprays nano-urea @ 8 ml /L (25 and 45 DAS)	62.55	93.01	155.56	40.2
9	25% RDN as basal + 1 spray nano-urea @ 6 ml /L (45 DAS)	53.57	85.26	138.83	38.58
10	25% RDN as basal + 1 spray nano-urea @ 8 ml /L (45 DAS)	53.95	86.14	140.09	38.51
	CD ($p \leq 0.05$)	3.875	5.213	7.766	2.044
	SEm ±	1.294	1.741	2.594	0.683
	CV (%)	3.685	3.319	2.961	2.961

Table 5: Impact of of different treatments of nano-urea on yield attributes of maize hybrid (SMH-5).

S. No.	Treatments	No. of cobs/plant	No. of rows/cob	No. of grains/cob	Seed index (g)
1	Control	1.22	12.21	21.97	26.36
2	Recommended dose of Nitrogen (RDN) as basal (prilled urea) @120 kg/ha	1.28	13.76	29.82	26.39
3	75% RDN as basal + 1 spray nano-urea @ 2 ml/L (45 DAS)	1.24	14	30.39	26.8
4	75% RDN as basal + 1 spray nano-urea @ 4 ml /L (45 DAS)	1.27	14.22	30.54	26.79
5	50% RDN as basal + 2 sprays nano-urea @ 2 ml /L (25 and 45 DAS)	1.29	14.6	32.08	26.88
6	50% RDN as basal + 2 sprays nano-urea @ 4 ml /L (25 and 45 DAS)	1.29	14.6	33.62	26.9
7	25% RDN as basal + 2 sprays nano-urea @ 6 ml /L (25 and 45 DAS)	1.24	13.62	27.58	26.56
8	25% RDN as basal + 2 sprays nano-urea @ 8 ml /L (25 and 45 DAS)	1.25	13.64	28.08	26.83
9	25% RDN as basal + 1 spray nano-urea @ 6 ml /L (45 DAS)	1.25	13.07	26.12	26.38
10	25% RDN as basal + 1 spray nano-urea @ 8 ml /L (45 DAS)	1.26	13.11	26.28	26.53
	CD ($p \leq 0.05$)	N/A	0.757	1.194	N/A
	SEm ±	0.018	0.253	0.399	0.397
	CV (%)	2.522	3.198	2.41	2.578

4.3 Nutrient-Use Efficiency and Quality

Highest agronomic efficiency (154.3 kg/kg N) and apparent recovery (116.1%) in T_8, physiological efficiency (97.4 kg/kg uptake) in T_6, and partial factor productivity (144.2 kg/kg N) in T7. Protein content increased to 11.58% (T_6/T7). Nano-urea reduced losses, improving N uptake (108–154% in grain) (Ajithkumar *et al*., 2021; Samanta *et al*., 2022) [2, 17].

4.4 Economics

Gross returns peaked at ₹163,401.2 (T_6, 78% over control), net returns ₹105,204.6 (175%), and B:C 1.81 (153%). Integrated nano-urea maximized profitability (Samui *et al*., 2022) [18].

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