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Effect of nano urea-based nitrogen management on growth, yield, and economics in safflower (*Carthamus tinctorius* L.)

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Abstract
Safflower (*Carthamus tinctorius* L.) is an important oilseed crop valued for its edible oil and industrial applications, but its productivity is often constrained by sub-optimal nitrogen (N) management. Nano urea, developed using nanotechnology, has emerged as a novel fertilizer with higher foliar absorption efficiency and potential to enhance crop productivity. A field experiment was conducted during the safflower growing season using a split-plot design with three replications to evaluate the effect of basal N levels and foliar application of nano urea on seed yield and economics. The treatments consisted of three basal N levels (100, 75, and 50% recommended dose of nitrogen, RDN) in main plots and five foliar sprays (no spray, nano urea at flowering, nano urea at flowering and seed filling, 2% urea at flowering, and 2% urea at flowering and seed filling) in sub-plots.
Results revealed that application of 100% RDN recorded the highest seed yield (1507 kg/ha), with a 33.6% and 43.4% advantage over 75% and 50% RDN, respectively. Among foliar treatments, nano urea spray at flowering and seed filling (N2) produced the highest seed yield (1667 kg/ha), representing a 70.8% increase over the control. Economic analysis indicated maximum gross returns with N2 (₹92,567/ha). The interaction effects were generally non-significant, though F1N2 tended to outperform other combinations.
The study demonstrates that nano urea foliar application, particularly at flowering and seed filling stages, enhances safflower productivity and profitability while improving nitrogen use efficiency. Integration of nano urea with reduced basal nitrogen offers scope for sustainable and resource-efficient nitrogen management in safflower.

Keywords: Nano urea, economics, nitrogen etc

Introduction
Safflower (*Carthamus tinctorius* L.) is an important oilseed crop cultivated in semi-arid regions, valued for its high-quality edible oil, medicinal properties, and industrial applications. Despite its resilience to drought, the productivity of safflower is often limited by sub-optimal nutrient management, particularly nitrogen (N), which is a key determinant of vegetative growth, capitula development, seed set, and oil accumulation. Conventional urea is the major source of nitrogen for safflower cultivation. These inefficiencies not only reduce crop yield but also increase production costs and pose environmental concerns.
Nano urea, a liquid fertilizer developed using nanotechnology, has emerged as a potential alternative to enhance nitrogen use efficiency in crops. With particle sizes below 100 nm, nano urea has a high surface area and enhanced reactivity, enabling rapid absorption through leaf stomata and cuticles. It supplies nitrogen more efficiently, reduces dependency on bulk urea, and improves plant metabolic activity. Foliar application of nano urea at critical growth stages can supplement or partially replace basal nitrogen application, thereby enhancing seed yield and reducing environmental losses.
However, systematic studies on safflower are limited, particularly regarding the combined effect of basal nitrogen application and foliar supplementation through nano urea in comparison with conventional urea sprays. Therefore, a field experiment was undertaken to quantify the effect of nano urea on seed yield and economic returns in safflower under varying levels of basal nitrogen management.

Objectives

The present investigation was carried out with the following objectives:

1. To evaluate the effect of basal nitrogen levels and foliar application of nano urea on growth and seed yield of safflower.
2. To assess the influence of nano urea on nitrogen use efficiency indices under different nitrogen management practices.
3. To analyse the economics of safflower production under nano urea-based nitrogen management strategies.

Materials and Methods

The experiment was laid out in a split-plot design with three replications. The treatments consisted of 15 treatment combinations of basal nitrogen application (main plots) and foliar spray of nano urea/urea (sub-plots):

Main plot - Fertilizer N application at basal/splits
F1: 100% Recommended Dose of Nitrogen (RDN)
F2: 75% RDN
F3: 50% RDN

Sub-plot - Foliar spray of nano urea/urea
N0: No spray of nano urea
N1: Nano urea spray at flowering stage
N2: Nano urea spray at flowering and seed filling stages
N3: Urea spray at 2% at flowering stage
N4: Urea spray at 2% at flowering and seed filling stages
This resulted in 15 treatment combinations (3 × 5).

Plot Details

Distance between rows: 45 cm
Gross plot size: 5.4 m × 6.0 m (12 rows, 6 m long)
Net plot size: 4.5 m × 5.6 m (10 rows, 5.8 m long)
Hectare conversion factor: 396.82
Date of harvest: As per maturity of crop

Results and Discussion

Effect of Fertilizer Nitrogen Levels

The pooled data (Table 1) revealed that basal nitrogen application significantly influenced growth and yield attributes of safflower. Application of 100% RDN (F1) resulted in maximum plant height (85.50 cm), number of capitula per plant (53.30), number of seeds per capitulum (27.00), and seed weight per plant (75.20 g). This was followed by 75% RDN (F2), while the lowest values were recorded under 50% RDN (F3).

Seed yield and biological yield were also significantly affected by basal nitrogen levels. The pooled seed yield was highest under F1 (1507 kg/ha), which was 33.6% higher than F2 (1128 kg/ha) and 43.4% higher than F3 (1050 kg/ha). Similarly, biological yield followed the same trend, with F1 recording 4487 kg/ha, compared to 3837 kg/ha under F2 and 3561 kg/ha under F3.

The increase in yield attributes and yield with higher basal nitrogen levels may be attributed to the positive role of N in promoting vegetative growth, capitula development, and seed setting. These results are in line with earlier findings of (Peddinti Anu Gayathri *et al*. 2023) [1] who reported that higher nitrogen doses enhance safflower productivity through improved source-sink relationships.

Effect of Foliar Application of Nano Urea/Urea

Significant differences were observed among foliar treatments for all growth and yield parameters (Table 2). The pooled data showed that N2 (nano urea spray at flowering and seed filling stages) produced the tallest plants (88.33 cm), maximum capitula per plant (60.00), highest number of seeds per capitulum (30.33), and maximum seed weight per plant (80.66 g).

In terms of yield performance, N2 recorded the highest pooled seed yield (1667 kg/ha), which was 70.8% higher than N0 (976 kg/ha) and 26.6% higher than N1 (1280 kg/ha). Biological yield was also maximum under N2 (4326 kg/ha), followed by N1 (4021 kg/ha). The economic analysis further confirmed the superiority of N2, with gross returns of ₹92,567/ha, compared to ₹71,118/ha under N1 and only ₹54,187/ha under the control (N0).

The improved performance of N2 can be attributed to the sustained supply of nitrogen during both flowering and seed filling stages, which are critical for capitula development and seed formation (Sharma, S.K. *et.al.*2022) [5]. The foliar application of nano urea ensured efficient absorption and assimilation, thereby enhancing nitrogen use efficiency and yield. Similar findings were reported by (S.A. Shinde et. al. 2023) [4] in oilseeds.

Interaction Effect

The interaction between basal nitrogen levels and foliar sprays was found to be non-significant for most of the traits, except biological yield in 2022-23. This suggests that the effect of foliar application of nano urea was consistent across basal nitrogen levels. However, the highest yields were generally obtained when 100% RDN was combined with nano urea sprays at flowering and seed filling (F1N2), indicating the additive benefits of integrated N management. (Gayathri, P.A.2022-23) [2]

Economics

Economically, the combination of N2 treatment with higher basal N produced the highest gross returns (₹92,567/ha). Even with reduced basal N (75%), supplementation with nano urea considerably improved returns compared to conventional urea sprays, demonstrating its viability for cost-effective safflower production.

Table 1: Nitrogen management in safflower through nano urea to improve productivity and nitrogen use efficiency (year 2021-22, 2022-23 and pooled

Treatments	Plant Height (cm)			Capitula No./ plant			No. of seed per capitula			Seed weight per plant (gm)		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
Fertilizer N Application												
F_1: 100% N	85.93	86.0	85.50	59.33	48.0	53.30	27.66	26.93	27.00	86.46	64.0	75.20
F_2: 75% N	85.26	85.0	84.80	57.06	46.4	51.40	26.60	26.20	26.30	81.26	61.0	70.70
F_3:50% N	81.46	81.7	81.10	53.46	44.8	48.90	23.80	23.60	23.60	78.60	56.6	67.20
S.Em±	0.76	0.7	0.05	0.63	0.8	0.73	0.41	0.48	0.10	0.72	0.9	0.40
C.D (p=0.05)	2.98	2.7	0.37	2.47	NS	NS	1.63	1.91	0.65	2.85	3.6	2.64

Foliar spray of Nano urea /urea												
N_0: No spray of Nano urea	80.88	81.2	80.66	48.55	37.4	42.66	20.88	20.22	20.33	73.33	44.4	58.50
N_1: Nano urea spray at flowering stage	84.00	84.1	83.50	50.77	40.7	45.60	28.11	28.44	28.16	84.55	64.5	74.00
N_2: Nano urea spray at flowering and seed filling stage	88.88	88.7	88.33	65.33	55.3	60.00	30.88	30.11	30.33	91.00	71.0	80.66
N_3: Urea spray at 2% at flowering stage	86.11	85.8	85.50	58.00	48.0	52.67	26.88	25.66	26.16	82.00	62.0	72.00
N_4: Urea spray at 2% at flowering and seed filling stage	81.22	81.5	81.00	60.44	50.4	55.00	23.33	23.44	23.16	79.66	60.7	70.00
S.Em±	1.15	1.1	0.21	1.38	1.5	0.76	0.60	1.0	0.35	0.68	0.9	1.24
C.D (p=0.05)	3.38	3.3	0.67	4.02	4.6	2.47	1.75	3.1	1.10	1.99	2.7	3.87
Interaction												
S.Em±	2.00	1.9	0.12	2.39	2.7	1.64	1.04	1.83	0.22	1.18	1.6	0.90
C.D (p=0.05)	NS	5.7	NS	NS	7.9	NS	NS	NS	NS	NS	NS	NS
C.V (%)	4.13	4.03	4.10	7.31	10.23	8.13	6.93	12.46	7.18	2.50	4.7	4.50
GM	85.93	84.3	83.79	56.62	46.4	51.20	26.02	25.57	25.63	82.11	60.5	71.03

Table 2: Nitrogen management in safflower through nano urea to improve productivity and nitrogen use efficiency (year 2021-22, 2022-23 and pooled

Treatments	Seed yield (kg/ha)			Biological Yield (Kg/ha)			Gross returns (Rs/ha)		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
Fertilizer N Application									
F_1: 100% N	1467	1548	1507	4434	4542	4487	79858	87469	83663
F_2: 75% N	1043	1214	1128	3753	3921	3837	56784	68620	62702
F_3:50% N	992	1109	1050	3516	3608	3561	54021	62684	58352
S.Em±	61	65	22	52	79	20	3370	3695	1099
C.D (p=0.05)	243	256	138	205	311	130	13229	14508	7205
Foliar spray of Nano urea /urea									
N_0: No spray of Nano urea	951	1001	976	3695	3983	3839	51794	56581	54187
N_1: Nano urea spray at flowering stage	1212	1350	1280	4039	4004	4021	65948	76287	71118
N_2: Nano urea spray at flowering and seed filling stage	1581	1754	1667	4249	4405	4326	86028	99107	92567
N_3: Urea spray at 2% at flowering stage	1052	1152	1101	3786	3893	3839	57264	65094	61179
N_4: Urea spray at 2% at flowering and seed filling stage	1042	1195	1118	3737	3832	3784	56736	67554	62145
S.Em±	46	62	20	50	95	59	2527	3526	1236
C.D (p=0.05)	136	182	62	148	280	186	7376	10293	3852
Interaction									
S.Em±	80	108	35	87.99	166	44	4377	6108	2459
C.D (p=0.05)	NS	NS	NS	NS	485	NS	NS	NS	NS
C.V (%)	11.94	14	4.05	3.91	7	9.02	11.93	14.51	12.10
GM	1467	1290	1229	3901	4023	3962	63554	72924	68239

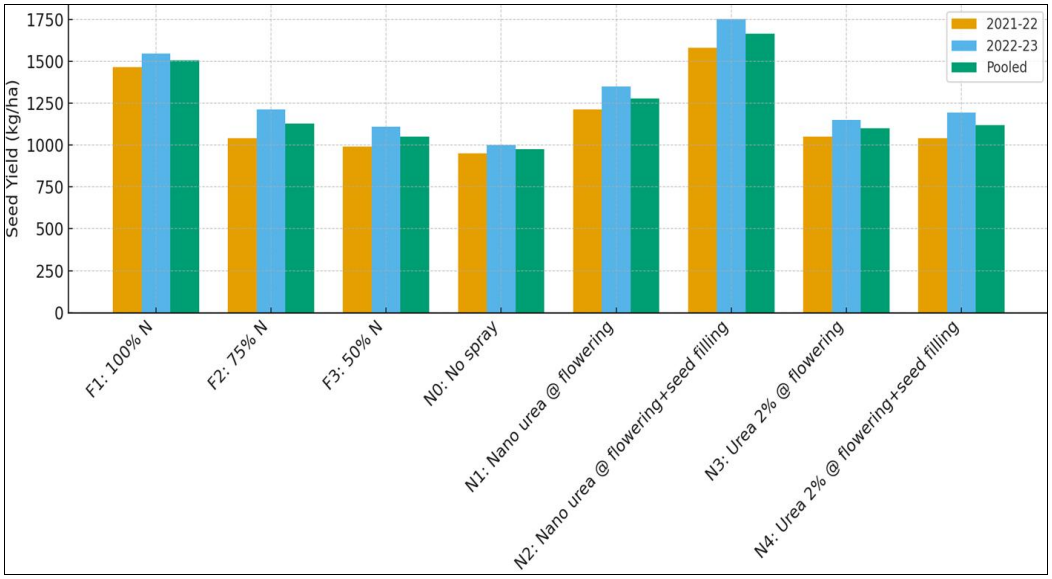

Fig: Graph of seed yield of safflower under different nitrogen management treatment

Conclusion

The pooled results over two years clearly demonstrate that nano urea sprays at flowering and seed filling stages (N2) significantly improved growth, yield attributes, seed yield, and economic returns of safflower compared to no spray or conventional urea sprays. Among basal N levels, 100% RDN (F1) recorded the highest yield; however, integration of nano urea sprays with reduced basal N (75%) also produced competitive yields.

Thus, the study establishes that nano urea can serve as an

efficient nitrogen management tool in safflower, enabling partial substitution of chemical fertilizers, enhancing nitrogen use efficiency, and improving profitability.

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