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RESEARCH PAPER

Nitrogen management in safflower [*Carthamus tinctorius* L.] through soil and foliar nutrition

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Abstract: A field experiment was conducted during *rabi* 2023 at the Regional Agricultural Research Station,Vijayapura, using a Factorial Randomized Complete Block Design with two controls, replicated thrice. The first factor consisted of soil application of three nitrogen levels: 100% Recommended Dose of Nitrogen (RDN), 75% RDN and 50% RDN and the second factor includes foliar applications of urea @ 2%, nano- urea @ 2 and 4 ml L^1 and no foliar spray (control). These twelve combinations were compared with two control treatments (Ghanajeevamrutha + jeevamrutha @ 20% and absolute control). The results indicated that the soil application of 100% RDN produced significantlyinfluenced on growth, yield and economics of safflower soil application of 100% RDN recorded significantly better growth, yield and economics compared to other levels of RDN application. Among the foliar application, nano-urea @ 4 ml L^{-1} recorded significantly higher growth, yield and economics. Among the interactions, treatment receiving 100% RDN along with foliar application of nano-urea @ 4 ml L^{-1} recorded significantly higher growth attributes *viz*., plant height (103.09 cm), number of primary and secondary branches $plant^{-1}$ (16.63 and 30.67), yield attributes *viz*., more seed yield $plant^{-1}$ (36.85 g), seed yield (1863 kg ha^{-1}) and stalk yield (4402 kg ha^{-1}) and net returns (₹ 67872 ha^{-1}) and B:C (2.86) compared to other combinations and absolute control.

Key words: Growth, Nano-urea, Nitrogen, Yield

Introduction

Safflower (*Carthamus tinctorius* L.), commonly known as kusum or kardi, is a winter oilseed crop cultivated in dry regions of Southern Asia, especially India. It belong to Asteraceae family, it thrives in harsh conditions like drought and cold, making it valuable for agriculture and industry. Safflower is grown for its orange-red dye, carthamin, and its oil, which contains 24-36 per cent oil content. The cold-pressed oil, rich in oleic and linoleic acid, is used in cooking and various industries, including pharmaceuticals and biofuel. Its deep tap-root system allows it to access water from deep soils, making it ideal for dry areas. In India, safflower is grown in an area of about 0.79 lakh hectares with a production of 0.61 lakh tonnes and productivity of 777 kg ha^{-1}. Karnataka and Maharashtra are the major safflower growing states, which contribute more than 90 per cent of India's production. In Karnataka, safflower is grown in an area of 0.42 lakh hectares with a production of 0.33 lakh tonnes and productivity of 809 kg ha-1 (Anon., 2021). In Karnataka, safflower is grown as a sole crop. Sometimes, it is grown as mixed crop in *rabi* sorghum and in chickpea as intercrop in medium to deep black soils of Kalaburagi, Vijayapura, Raichur, Bellary and Dharwad district.

Nitrogen is crucial for the formation of chlorophyll and enzymes, which are essential for the plant's physiological processes (Hellal and Abdelhamid *et al*., 2013). Proper nutrient management is vital for healthy plant growth. Safflower production faces challenges from pests, diseases and environmental stress, making pest control and sustainable farming important for better yields. Low yields in India are often due to poor soil, unbalanced nutrient availability and water shortages in dry regions. Limited nutrient availability at planting and external factors reduce nutrient uptake as the crop matures. To overcome this, foliar nutrient sprays at key growth stages help improve nutrient use and overall crop performance (Heidari and Asad, 1998; Dordas and Sioulas, 2009).

Nano fertilizers are becoming popular due to their small size and unique properties. Nano-based agriculture shows potential for boosting crop yields while lowering the environmental impact of traditional fertilizers (Milani *et al.,* 2012). However, there is still a lack of detailed studies on how nano fertilizers, either alone or combined with regular fertilizers, affect crop growth, yield and economic outcomes in real field conditions (Kah *et al*., 2018; Mullen, 2019). Considering this, the present study aims to explore the benefits of nano-urea on safflower productivity.

Material and methods

A field experiment was conducted during the *rabi* season of 2023 at the Regional Agricultural Research Station,Vijayapura, Karnataka on vertisols having an alkaline in reaction (pH 8.18), low salinity (0.30 dSm^{-1}), medium organic carbon (0.41%), low in available nitrogen (180.20 kg N ha^{-1}), medium in available phosphorus (30.40 kg P_2O_5 ha^{-1}) and high in available potassium (418.00 kg K_2O ha^{-1}). The experimental site was located at a latitude of $16^0 45' 51''$ North, longitude of $75^0 44' 46''$ East and an altitude of 593.8 meters above mean sea level in Northern Dry Zone of Karnataka (Zone 3). The normal annual rainfall for the past 30 years was 594.4 mm in 38 rainy days. The highest normal rainfall was 151.6 mm received in the month of September in 8 rainy days. A total of 327 mm of rainfall was received during the cropping year 2023, which was 267 mm lower than the normal.

September month received highest rainfall (98.0 mm) followed by July (92.0 mm). The normal monthly maximum air temperature was highest in the month of May (39.1°C), while it was lowest in the month of December (29.1°C). During the cropping year the higher maximum air temperature was recorded in May (38.2°C) and lower was recorded in December (29.5°C)

The experiment was laid out in Factorial Randomized Complete Block Design with two controls, replicated thrice. The first factor consisted of soil application of three nitrogen levels: 100% Recommended Dose of Nitrogen (RDN), 75% RDN and 50% RDN and the second factor includes foliar applications of urea @ 2%, nano- urea @ 2 and 4 ml L^{1} and no foliar spray (control). These twelve combinations were compared with two control treatments (Ghanajeevamrutha + jeevamrutha @ 20% and absolute control). The land was ploughed once after the harvest of the previous crop, followed by two harrowing. At the time of sowing, the land was prepared to a fine seed bed and the plots were laid out. The variety A-2020 was used in the study. The fertilizer like Nitrogen, phosphorus, potassium, sulfur, and zinc were applied at sowing as per recommendations, using urea, diammonium phosphate, muriate of potash, sulfur, and zinc sulfate. Foliar sprays of urea, nano-urea, and jeevamrutha were applied at 25-30 and 55-60 days after sowing and no fertilizers was applied to absolute control. The crop was sown with a spacing of 60 × 30 cm. To protect the crop from pests, spraying of thiamethoxam 25% WG and Emamectin Benzoate 5% SG against aphids and Helicoverpa during 45 and 60 days after sowing. Harvesting was done at the physiological maturity of the crop. The net plot area (25.92 m^2), as per the treatments, was harvested by cutting the plants to the ground level.After complete drying, the harvested produce was weighed just before threshing to record seed weight per plot. Thereafter, threshing was done manually. The threshed produce was winnowed and cleaned to separate seed and stalk.

Five plants were randomly selected in each treatment in the net plot area and labelled with tags to record various growth and yield parameters observations. Periodical observations were taken in these plants at 30, 60, 90 DAS and harvest. The plant height was measured from the ground level to the tip of the main shoot. Whereas the total number of branches in each plant was counted from five randomly selected plants and then the mean value for each treatment was determined. The yield attributes and yield were recorded from the net plots and seed yield was converted to hectare basis in kilograms.

The economics of each treatment was computed with minimum support price of the corresponding year (2023). The yield was further computed for gross and net returns as well BC ratio to assess the profitability. The benefit-cost ratio was worked out by dividing the gross returns by the total cost of cultivation of respective treatments. The data collected from the experiment at different growth stages and at harvest were subjected to statistical analysis as described by Gomez and Gomez (1984). The level of significance used for 'F' and 't' tests was P=0.05. Critical Difference (CD) values were calculated at 5 per cent probability level if the F test will found to be significant.

Table 1. Plant height, primary and secondary branches per plant at harvest as influenced by nitrogen management in safflower

Treatments	Plant height (cm)	Primary branches per plant	Secondary branches per plant
Factor. I- Nitrogen doses (A)			
A_1 - 100% RDN	93.50	14.72	27.99
A_2 - 75% RDN	84.62	12.94	24.31
A_3 - 50% RDN	78.21	11.24	21.44
S.Em±	1.69	0.24	0.43
C.D. (p=0.05)	4.97	0.69	1.26
Factor. II- Foliar spray (B)			
B_1 - No spray	80.11	11.61	22.39
B_2 - Urea @ 2%	81.85	12.55	23.72
B_3 - Nano-urea @ 2 ml L^{-1}	87.30	13.54	25.38
B_4 - Nano-urea @ 4 ml L^{-1}	92.51	14.15	26.82
S.Em±	1.96	0.27	0.49
C.D. (p=0.05)	5.74	0.80	1.45
Interaction (A×B)			
A_1B_1	83.09	12.87	24.74
A_1B_2	86.46	13.36	26.84
A_1B_3	101.35	16.00	29.69
A_1B_4	103.09	16.63	30.67
A_2B_1	80.18	12.00	21.89
A_2B_2	81.28	12.87	22.70
A_2B_3	82.01	12.90	24.66
A_2B_4	95.03	13.97	27.98
A_3B_1	77.05	9.97	20.55
A_3B_2	77.82	11.43	21.63
$A_3B\text{-}_3$	78.56	11.73	21.79
A_3B_4	79.40	11.83	21.80
S.Em+	3.39	0.47	0.86
C.D. (p=0.05)	9.94	1.38	2.51
Control (C)			
C_1 - Ghanajeevamrutha 1 t ha^{-1} + Jeevamrutha @ 20%	76.00	11.97	20.88
C_2 – Absolute control	69.96	10.73	17.70
S.Em±	3.73	0.49	0.85
C.D. (p=0.05)	10.85	1.43	2.47

Note: RDN- Recommended dose of nitrogen

Results and discussion

Effect of soil application of nitrogen levels

Decreasing levels of nitrogen soil application significantly decreased growth attributes like plant height, number of primary and secondary branches per (Table 1). The treatment receiving soil application of 100% RDN recorded a significantly higher plant height (93.50 cm), number of primary and secondary branches per (14.72 and 27.99) compared to 50% RDN (78.21 cm, 11.24 and 21.44, respectively) The increase of plant height in the treatment 100% RDN levels may be nitrogen promotes leaf and stem growth by aiding in the formation of proteins and chlorophyll. Promoting cellular processes, photosynthesis and nutrient uptake. The results of the present study align with Ebrahimian and Soleymani (2013), who found that soil application of 100% recommended dose of NPK recorded the maximum yield attributes in safflower, conversely, nutrient shortages leads to decreased values. Several researchers, including Dordas and Sioulas (2009), found that higher doses of RDN fertilizer significantly influenced growth and yield attributes in safflower.

Yield attributes *viz*.,number of capitula plant^{-1}, seed weight plant^{-1}, number of seeds capitulam^{-1} were increased significantly with soil application of different levels of nitrogen (Table 2). In the present study treatment consisting of 100% RDN recorded a significantly higher number of capitula plant^{-1} (25.80), number of seeds capitulam^{-1} (21.25) and seed yield per plant (33.71 g) compared to 50% RDN (20.09, 15.98 and 18.76, respectively). The increase in yield attributes due to nitrogen are particularly indispensable for boosting healthy vegetative growth and optimal grain development in safflower cultivation. These nutrients contribute significantly to the plant's metabolic processes, chlorophyll synthesis, energy production and root establishment (Gayathri *et al*., 2023).

The seed and stalk yield of safflower were significantly influenced by soil application of RDN levels (Fig 1). The treatment receiving basal nutrient levels of 100% RDN exhibited a significantly higher seed and stalk yield (1675 and 4011 kg ha^{-1}) compared to 50% RDN levels (851 and 2233 kg ha^{-1}). The lower nutrient levels might have limited protein synthesis, enzymatic activity and energy transfer. This could lead to slightly reduced stalk growth and yield. The further reduced level and absence of RDN soil application could severely restrict protein synthesis, enzyme activity, root development and energy transfer. These limitations could greatly hinder overall plant growth, resulting in significantly reduced stalk yield. Similar findings were reported by Bitarafan *et al*. (2011), Sepideh *et al*. (2011), Forooghi and Ebadi (2012), Mohamed *et al*. (2012), Malek and Ferri (2014) in safflower.

Table 2. Number of capitula plant^{-1}, number of seeds capitulum^{-1}and seed yield plant^{-1} as influenced by nitrogen management in safflower.

Treatments	Number of capitula plant^{-1}	Number of seeds apitulum^{-1}	Seed yield (g plant^{-1})
Factor. I- Nitrogen doses (A)			
A_1 - 100% RDN	25.80	21.25	33.71
A_2 - 75% RDN	22.08	18.26	27.22
A_3 - 50% RDN	20.09	15.98	18.76
S.E m±	0.48	0.34	0.55
C.D.(p=0.05)	1.39	1.00	1.61
Factor. II- Foliar spray (B)			
B_1 - No spray	20.28	16.62	22.59
B_2 - Urea @ 2%	21.93	17.83	25.06
B_3 - Nano-urea @ 2 ml L^{-1}	23.48	19.21	28.41
B_4 - Nano-urea @ 4 ml L^{-1}	24.94	20.32	30.20
S.E m±	0.55	0.39	0.63
C.D.(p=0.05)	1.61	1.15	1.85
Interaction (A×B)			
A_1B_1	21.83	17.93	29.33
A_1B_2	23.86	20.40	32.30
A_1B_3	28.11	23.24	36.36
A_1B_4	29.40	23.41	36.85
A_2B_1	20.90	16.86	21.63
A_2B_2	21.42	17.42	25.30
A_2B_3	21.53	17.83	28.60
A_2B_4	24.47	20.93	33.36
A_3B_1	18.10	15.07	16.80
A_3B_2	20.52	15.68	17.59
$A_3B\text{-}_3$	20.81	16.57	20.26
A_3B_4	20.94	16.60	20.40
S.Em+	0.95	0.68	1.10
C.D. (p=0.05)	2.79	2.00	3.21
Control (C)			
C_1 - Ghanajeevamrutha 1 t ha^{-1} + Jeevamrutha @ 20%	20.00	16.00	17.06
C_2 – Absolute control	10.84	10.13	12.20
S.Em±	0.98	0.71	1.05
C.D. (p=0.05)	2.86	2.05	3.07

Economic parameters, like gross returns, net returns and benefit-cost ratio (BCR), increased with RDN application and maximized at the highest level (Table 3). It might be attributed to increased seed and stalk yields with soil application of RDN levels. The value of the increased yield was much more than the cost of nutrients, which increased the net returns and BCR. In our study, soil application of different levels of RDN had a significant effect on gross returns, net returns and BCR was recorded with treatment receiving the soil application of 100% RDN levels (₹ 93807 ha^{-1}, ₹ 58327 ha^{-1} and 2.64, respectively), compared to 50% RDN levels (₹ 47683 ha^{-1}, ₹ 12359 ha^{-1} and 1.35, respectively). Similar findings were also reported by Gaythri *et al*. (2023).

Effect of foliar spray of nitrogen

The foliar sprays of nitrogen significantly influenced the growth attributes (Table 1). The increased plant height, number of primary and secondary branches per plant were recorded with foliar application of nano-urea @ 4 ml L^{-1} (92.51 cm, 14.15 and 26.82, respectively), which was on par with nano-urea @ 2 ml L^{-1} (87.30 cm, 13.54 and 25.38, respectively) compared to no spray treatments.This positive improvement may be due to the application of nano urea, which increases tryptophan in meristematic cells that provokes auxins resulting in higher plant height. Similar findings were reported by Gayathri *et al* (2023) in safflower, Goud *et al*. (2022) in Sunflower and Nget *et al*. (2022) in soybean.

Foliar application of nitrogen also significantly influenced seed yield and stalk yield. The foliar spray of nano-urea @ 4 ml L^{-1} produced significantly higher seed and stalk yield (1490 and 3604 kg ha^{-1}, respectively), which was on par with nano-urea @ 4 ml L^{-1} (1387 and 3380 kg ha^{-1}, respectively) compared to other treatments (Fig 1). The higher seed yield and stalk yield might be due to more number of capitula per plant (24.94), seed yield per plant (30.20g) and number of seeds per capitulam (20.32 g) (Table 2). This might be due to nano-fertilizers integrating nanoscale devices to harmonize the controlled release of nitrogen fertilizers with their absorption by crops DeRosa *et al*. (2010). Higher concentrations of nano fertilizer lead to larger area, making it easier for the leaves to absorb more nutrients when sprayed.

The foliar application of nano-urea also significantly influenced gross returns, net returns and BCR. The foliar spray

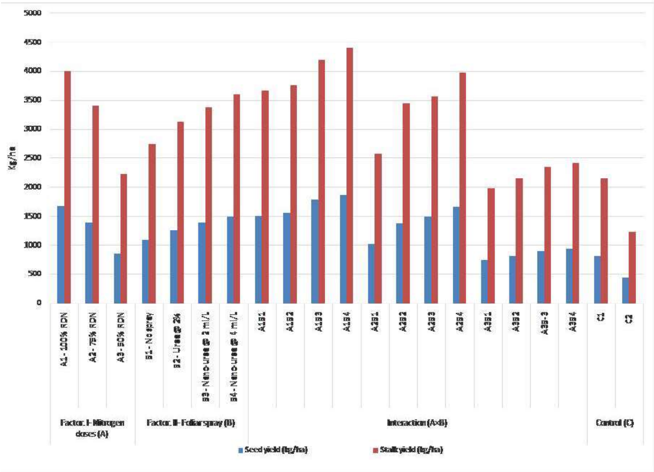

Fig 1. Seed yield and stalk yield as influenced by nitrogen management in safflower.

of nano-urea @ 4 ml L^{-1} produced significantly higher gross returns (83422 ₹ ha^{-1}), net returns (47060 ₹ ha^{-1}) and BCR (2.29) compared to no foliar spray. However, it was on par with foliar spray of nano-urea @ 2 ml L^{-1} (77679 and 42097 ₹ ha^{-1} and 2.18 respectively. This might be attributed to the lower cost of cultivation and the highest seed yield with foliar sprays that influenced the economics. Similar findings were also reported by Gayathri *et al*. (2023).

Effect of soil and foliar application of nitrogen

Combined soil and foliar application of nitrogen increased the growth attributes like plant height and number of primary and secondary branches per plant at harvest in the safflower (Table 1). The treatment combination of 100% RDN + nano-urea @ 4 ml L^{-1} produced significantly taller plants, number of primary and secondary branches per plant, (103.09 cm, 16.63, 30.67, respectively), which was on par with 100% RDN + nano-urea @ 2 ml L^{-1}(101.35 cm, 16.00, 29.69, respectively) compared to other combination and control treatments significantly decrease the plant height, number of primary and secondary branches per plant of the safflower. Similarly, plant height, number of primary and secondary branches per plant was also shown higher in the order of treatment receiving soil application of 100% RDN + nano-urea @ 4 ml L^{-1} > 100% RDN + nano-urea @ 2 ml L^{-1} > 75% RDN + nano-urea @ 4 ml L^{-1}. Soil-applied nitrogen fertilizers provide a steady supply of nutrients for vegetative growth, increasing branching. Foliar nano-urea application boosts phosphorus availability during the reproductive phase, promoting flower development, which leads to more capitula and better seed set. This combined approach ensures optimal nutrient availability throughout the plant's life cycle, from growth to reproduction. While soil-applied nitrogen supports early plant development, foliar nano-urea fine-tunes nutrient supply during the important flowering and seed-filling stages.These results are in close conformity with those of Ajithkumar *et al.* (2021) and Gayathri *et al.* (2023).

Safflower yield, resulting from various yield attributes, was significantly affected by soil and foliar application of nitrogen (Fig 1). Among different treatment combinations, the maximum seed yield of 1863 kg ha^{-1} and stalk yield of 4402 kg ha^{-1} of safflower was recorded with soil application of 100% RDN along with foliar spray of nano-urea @ 4 ml L^{-1}. Thereafter upon decreasing 25% of the recommended dose of nitrogen (100% RDN) with a combination of 100% RDN along nano-urea @ 2 ml L^{-1} foliar sprays reduced seed yield and stalk yield with a tune of 20.02% and 18.88%, respectively. The drastic decrease in seed yield and stalk yield of 59.69% and 54.79% in 50% RDN + no spray application treatment compared to 100% RDN + foliar spray of nano-urea @ 4 ml L^{-1}. This indicates that plants require optimum nutrient levels to get better growth and yield. The cumulative beneficial effect of yield attributing characters is also finally reflected in the seed yield. Like seed and stalk yield, the same treatment receiving the soil application of 100% RDN with foliar spray of nano-urea @ 4 ml L^{-1} produced better yield attributes like the number of capitula per plant (29.40), number of seeds per capitula (23.41) and seed weight per plant

Table 3. Cost of cultivation, gross returns, net returns and benefit cost ratio (BCR) as influenced by nitrogen management in safflower.

Treatments	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	BCR
Factor. I- Nitrogen doses (A)				
A_1 - 100% RDN	35480	93807	58327	2.64
A_2 - 75% RDN	35402	77765	42363	2.19
A_3 - 50% RDN	35324	47683	12359	1.35
S.Em±	-	1835	1835	0.05
C.D. (p=0.05)	-	5381	5381	0.14
Factor. II- Foliar spray (B)				
B_1 - No spray	34802	61110	26308	1.76
B_2 - Urea @ 2%	34862	70130	35268	2.01
B_3 - Nano-urea @ 2 ml L^{-1}	35582	77679	42097	2.18
B_4 - Nano-urea @ 4 ml L^{-1}	36362	83422	47060	2.29
S.Em±	-	2118	2118	0.06
C.D. (p=0.05)	-	6213	6213	0.17
Interaction (A×B)				
A_1B_1	34880	84412	49532	2.42
A_1B_2	34940	87239	52299	2.50
A_1B_3	35660	99267	63607	2.78
A_1B_4	36440	104312	67872	2.86
A_2B_1	34802	56855	22053	1.63
A_2B_2	34862	77511	42649	2.22
A_2B_3	35582	83425	47843	2.34
A_2B_4	36362	93271	56909	2.56
A_3B_1	34724	42062	7338	1.21
A_3B_2	34784	45639	10855	1.31
$A_3B\text{-}_3$	35504	50345	14841	1.42
A_3B_4	36284	52685	16401	1.45
S.Em±	-	3669	3669	0.10
C.D. (p=0.05)	-	10762	10762	0.29
Control (C)				
C_1 - Ghanajeevamrutha 1 t ha^{-1} + Jeevamrutha @ 20%	31289	45547	14258	1.46
C_2 - Absolute control	21395	24433	3038	1.14
S.Em±	-	3427	3427	0.09
C.D. (p=0.05)	-	9962	9962	0.27

Note: RDN- Recommended dose of nitrogen

(36.85 g), which was on par with 100% RDN + nano-urea @ 2 ml L^{-1} combination (Table 2). These results are in close conformity with those of Ajithkumar *et al.* (2021), Ebrahimian and Soleymani (2013).

The combined interactions between soil application of RDN levels and foliar application of nano-urea increased the gross returns, net returns and BCR. The interaction treatment receiving the soil application of 100% RDN + foliar spray of nano-urea @ 4 ml L^{-1} recorded highergross returns (104312 ₹ ha^{-1}), net returns (67872 ₹ ha^{-1}) and BCR (2.86), which was on par with 100% RDN + foliar spray of nano-urea @ 4 ml L^{-1} (99267, 63607 and 2.78, respectively) compared to other combination and control treatments (Table 3). This could be attributed to the higher seed yield of safflower and the reduction in the cost of cultivation. These results are in conformity with the findings of Gayathri *et al*. (2023).

Conclusion

The soil application of 100% RDN combined with a foliar spray of nano-urea @ 2-4 mlL^{-1} enhances growth, yield attributes, overall yield and results in maximum net returns and an improved benefit-cost ratio in safflower cultivation.

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