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Effect of nano DAP on growth and yield of safflower (*Carthamus tinctorius* L.)

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Abstract
A field experiment was conducted at ICAR- Krishi Vigyan Kendra, Hagari during *rabi*, 2024 to study the effect of nano DAP on growth and yield of safflower. The experiment was laid in RCBD with nine treatments and replicated thrice. The results revealed that 100% RDF combined with foliar spray of nano DAP @ 2 ml l^{-1} at 30 and 45 DAS recorded significantly higher growth parameters *viz*., plant height, number of leaves, number of primary branches, number of secondary branches, leaf area per plant, leaf area index, dry matter production and its accumulation in different plant parts, yield parameters *viz*., number of capitulum $plant^{-1}$, number of seeds $capitulum^{-1}$, seed weight $plant^{-1}$, seed yield (1675 kg ha^{-1}), stover yield (3210 kg ha^{-1}). Further, it was found on par with 75% RDF combined foliar spray of nano DAP @ 2 ml l^{-1} at 30 and 45 DAS. Whereas, lower growth and yield parameters were recorded with foliar spray of nano DAP @ 4 ml l^{-1} at 30 DAS.

Keywords: Safflower, nano DAP, growth, yield

Introduction
Safflower (*Carthamus tinctorius* L.) is an oilseed crop, a member of the Compositae or Asteraceae family. Safflower is considered to be ideal for cosmetics, paint and varnish, soap, alkyd resins, waterproof leather bucket, roghans to preserve leather, glass cement industry. Safflower oil meal is a good feed cake that has the potential to be used as a human food if the bitter principles are removed. Safflower oil is renowned for its high content of monounsaturated and polyunsaturated fatty acids, offering notable cardiovascular health benefits. It is also used in various industrial applications, including cosmetics and pharmaceuticals.

Nano fertilizers mark a revolutionary step forward in agriculture, bringing greater efficiency and sustainability to nutrient delivery. By leveraging nanotechnology, these fertilizers are engineered with particles at the nanometre scale, greatly enhancing their solubility and availability to plants. One of their key benefits is the ability to deliver nutrients precisely and release them in a controlled manner, which boosts nutrient absorption by crops while minimizing waste. As a result, nano fertilizers not only increase crop yields but also reduce the environmental footprint compared to traditional fertilizers.

Nano DAP (Liquid) is a source of nitrogen and phosphorus. Along with nitrogen, phosphorus is also an important plant nutrient. Phosphorus (P) is vital for plant growth and is found in every living plant cell. It is involved in several key plant functions, including energy transfer, photosynthesis, transformation of sugars and starches, nutrient movement within the plant and transfer of genetic characteristics from one generation to the next.

Nano DAP foliar spray represents a significant advancement in agricultural nutrition, offering enhanced benefits over conventional fertilizers. This innovation involves the application of nutrient particles at the nanoscale, which dramatically increases their solubility and bioavailability. The primary advantage of nano DAP foliar spray is its ability to deliver essential nutrients like nitrogen and phosphorus directly to the plant leaves. This targeted application ensures that nutrients are efficiently absorbed and utilized, leading to improved plant growth and development. Keeping these points in view, the present investigation is planned to carry out to study the with an objective to study the effect of nano DAP on growth and yield of safflower.

Materials and Methods: The experiment was conducted during *rabi*, 2024 at Krishi Vigyan Kendra, Hagari (UAS, Raichur) which is situated in Northern Dry Zone of Karnataka (Zone-III) at Latitude of 15º 13′ North, Longitude of 77º 05′ East with an Altitude of 414 meters above mean sea level. The soil sample of the experimental site was medium deep clay soil in texture.

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications and nine treatments. The treatments are $T_{1:}$ 100% RDF + foliar spray of 2ml l^{-1} of nano DAP at 30 DAS and 45 DAS, $T_{2:}$ 75% RDF + foliar spray of 2ml l^{-1} of nano DAP at 30 DAS and 45 DAS, $T_{3:}$ 50% RDF + foliar spray of 2ml l^{-1} of nano DAP at 30 DAS and 45 DAS, $T_{4:}$ 100% RDF + foliar spray of 4ml l^{-1} of nano DAP at 30 DAS, $T_{5:}$ 75% RDF + foliar spray of 4ml l^{-1} of nano DAP at 30 DAS, $T_{6:}$ 50% RDF + foliar spray of 4ml l^{-1} of nano DAP at 30 DAS, $T_{7:}$ 100% RDF, $T_{8:}$ 100% RDF + 2% DAP foliar spray at 30 DAS and $T_{9:}$ Foliar spray of 4ml l^{-1} of nano DAP at 30 DAS. The safflower variety used was ISF-764, It is a high-yielding, rainfed cultivar developed by the ICAR-Indian Institute of Oilseeds Research (IIOR), Hyderabad, released in 2019. This variety gives red and yellow flowers with more branching and with a spacing of 60 cm x 30 cm.

During the course of investigation, in order to know the effect of nano DAP on growth parameters of safflower, the observations were recorded at different stages of the crop growth.

Results and discussion

Growth Parameters: Plant height (cm): The application of 100% RDF + foliar spray of nano DAP @ 2 ml l^{-1} at 30 and 45 DAS (21.90, 45.90, 90.04 and 94.07 cm, respectively) resulted in the taller plants at all the stages of crop growth like 30 DAS, 60 DAS, 90 DAS and at harvest. It was found on par with 75% RDF + foliar spray of nano DAP @ 2 ml l^{-1} at 30 and 45 DAS (19.50, 43.56, 89.23 and 93.13 cm, respectively) at 30 DAS, 60 DAS, 90 DAS and at harvest. Conversely, the foliar spray of nano DAP @ 4 ml l^{-1} at 30 DAS (16.34, 24.85, 55.78 and 58.32 cm, respectively) exhibited the dwarf plants at all the stages of crop growth. (Table 1).

The marked increase in plant height under higher levels of RDF combined with foliar application of nano DAP can be attributed to the balanced and timely supply of essential nutrients, especially nitrogen and phosphorus. Nano DAP, owing to its ultra-small particle size and larger surface area, enhances nutrient absorption through foliage and facilitates rapid translocation within plant tissues. Nitrogen supports the synthesis of amino acids and proteins, promoting cell division and elongation, which result in increased stem growth. Likewise, phosphorus improves root development and energy transfer, ensuring better water and nutrient uptake, which ultimately stimulates vegetative growth. The superior plant height recorded with combined RDF and nano DAP treatments aligns with findings reported by Rattan and Ruiqiang (2014), Drostkar *et al.* (2016) and Sannathimmappa *et al.* (2023) [4, 19, 20].

Number of leaves per plant

The higher number of leaves was observed with the application of 100% RDF + foliar spray of nano DAP @ 2 ml l^{-1} at 30 and 45 DAS (17.59, 65.89, 159.65 and 155.43, respectively), which was on par with 75% RDF + foliar spray of nano DAP @ 2 ml l^{-1} at 30 and 45 DAS (16.86, 63.34, 155.78 and 152.90, respectively) at all the stages of crop growth like 30 DAS, 60 DAS, 90 DAS and at harvest. Conversely, the foliar spray of nano DAP @ 4 ml l^{-1} at 30 DAS remained the least productive in terms of leaf count (10.91, 39.07, 100.23 and 96.45, respectively). (Table 1).

The enhanced leaf production under higher RDF levels combined with foliar nano DAP can be attributed to improved nutrient availability, which promotes vigorous vegetative growth and node formation. Foliar application of nano DAP significantly increased the photosynthetic efficiency by providing readily available nitrogen and phosphorus, which are vital for chlorophyll synthesis and leaf expansion. Nanoparticles facilitate rapid nutrient uptake through leaf surfaces and enhance nutrient mobility within the plant system, resulting in higher biomass and leaf proliferation. This is in line with the results of Merghany *et al.* (2019), Gondi (2018), Gewaily *et al.* (2019), Mehta and Bharat (2019) and Naveen *et al.* (2022) in various crops [5, 6, 13, 14, 15].

Leaf area (dm^2 plant^{-1})

The maximum leaf area was recorded in the treatment with 100% RDF + foliar spray of nano DAP @ 2 ml l^{-1} at 30 and 45 DAS (13.93, 35.67, 44.96 and 41.66 dm^2 plant^{-1}, respectively), which was statistically on par with 75% RDF + foliar spray of nano DAP @ 2 ml l^{-1} at 30 and 45 DAS (12.88, 34.55, 43.22 and 40.90 dm^2 plant^{-1}, respectively) at all the stages of crop growth like 30 DAS, 60 DAS, 90 DAS and at harvest. In contrast, the foliar spray of nano DAP @ 4 ml l^{-1} at 30 DAS consistently recorded the lower leaf area (10.67, 22.01, 28.31 and 26.61 dm^2 plant^{-1}, respectively) (Fig 1).

The significantly larger leaf area in treatments combining RDF with foliar spray of nano DAP is due to enhanced nitrogen and phosphorus availability during critical vegetative stages. Nano DAP supplies nitrogen in a highly available form, which supports chlorophyll synthesis and leaf expansion, while phosphorus aids energy transfer and cellular development. A higher leaf area improves light interception and photosynthetic rate, leading to robust growth and biomass accumulation. The improved nutrient use efficiency of nano formulations allows greater foliar absorption and targeted nutrient delivery, which reduces losses and promotes sustained leaf development. These results are in line with Rajesh *et al.* (2021), Vadlamudi *et al.* (2022), Manikandan and Subramanian (2016) and Torabian *et al.* (2017) [11, 18, 21, 22].

Total dry matter production (g plant^{-1})

Significantly higher total dry matter production was recorded in the treatment 100% RDF + foliar spray of nano DAP @ 2 ml l^{-1} at 30 and 45 DAS at 30 DAS, 60 DAS, 90 DAS and at harvest (11.63, 63.76, 89.76 and 146.84 g plant^{-1}, respectively) compared to other treatments, except the treatment with 75% RDF + foliar application of nano DAP @ 2 ml l^{-1} at 30 and 45 DAS (10.82, 61.07, 87.77 and 143.15 g plant^{-1}, respectively). The lowest dry matter accumulation was observed in the treatment which received only foliar spray of nano DAP @ 4 ml l^{-1} at 30 DAS (10.04, 31.52, 51.54 and 89.72 g plant^{-1}, respectively) at all the stages of crop growth. (Fig 2).

The enhanced total dry matter production can be attributed to the ample availability of essential nutrients fostering vigorous plant growth and development. The foliar application of nano-sized nitrogen and phosphorus facilitated rapid nutrient absorption due to their increased surface area and reactivity, providing more active sites for metabolic processes within the plant system. This resulted in augmented photosynthetic efficiency, larger leaf area, and robust vegetative growth, ultimately increasing biomass and seed yield, and culminating in higher total dry matter accumulation. Similar findings were also reported by Korishettar (2016) and Luma and Ahmed (2021) [8, 9].

Table 1: Plant height and number of leaves per plant of safflower as influenced by different levels of RDF and foliar application of nano DAP

Treatment	Plant height (cm)				No. of leaves per plant			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
T_1	21.90	45.90	90.04	94.07	17.59	65.89	159.65	155.43
T_2	19.50	43.56	89.23	93.13	16.86	63.34	155.78	152.90
T_3	18.21	31.19	68.33	72.87	14.25	46.11	124.89	122.04
T_4	20.34	40.38	82.12	87.13	17.16	58.58	147.12	145.22
T_5	19.20	39.45	81.55	86.76	15.42	57.39	143.66	140.65
T_6	18.01	28.04	61.45	65.88	13.12	41.76	116.43	114.39
T_7	20.22	35.81	74.31	79.87	16.90	50.12	133.07	130.17
T_8	21.87	36.12	75.09	80.76	16.36	52.25	135.89	132.56
T_9	16.34	24.85	55.78	58.32	10.91	39.07	100.23	96.45
S.Em. ±	**1.14**	**0.98**	**1.94**	**1.97**	**0.55**	**1.33**	**2.54**	**2.44**
C.D. (P=0.05)	**NS**	**2.93**	**5.80**	**5.90**	**1.64**	**3.98**	**7.62**	**7.33**

Note: RDF- Recommended doses of fertilizers (40: 40: 12.5 - N: P_2O_5: K_2O kg ha^{-1}), DAP- Di-ammonium Phosphate, DAS- Days after sowing

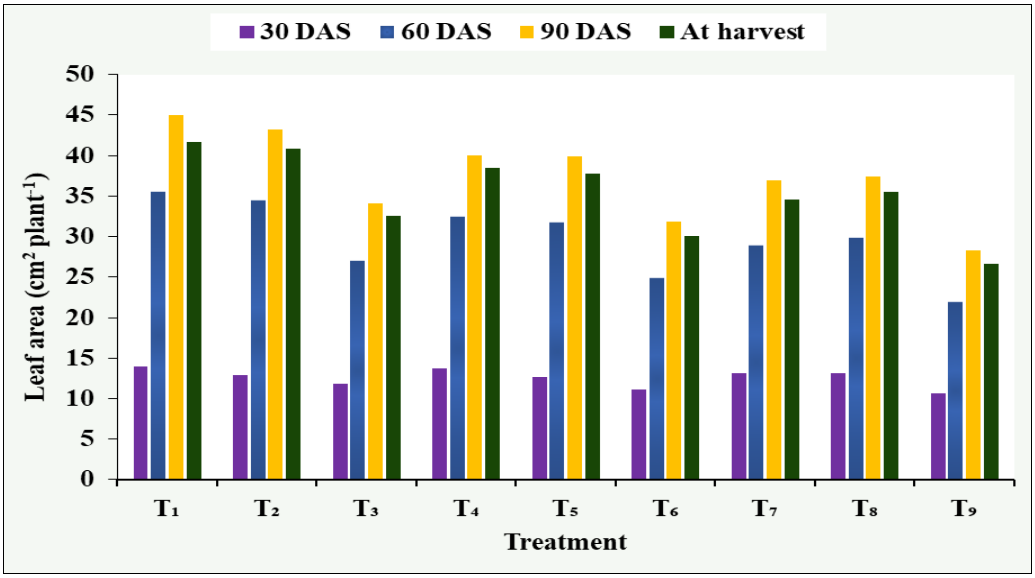

Fig 1: Leaf area at different growth stages of safflower as influenced by different levels of RDF and foliar application of nano DAP

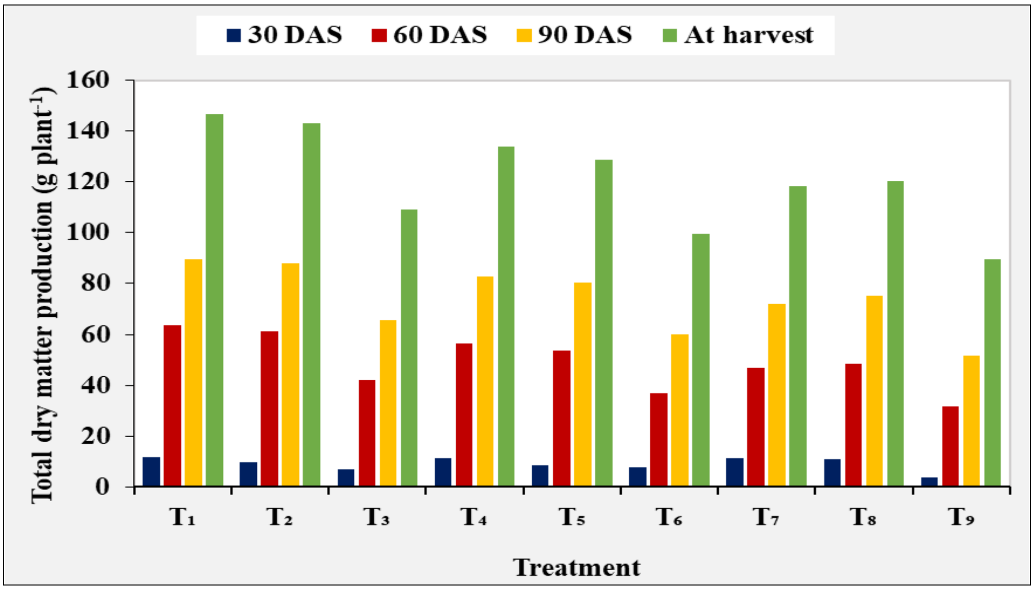

Fig 2: Total dry matter production at different growth stages of safflower as influenced by different levels of RDF and foliar application of nano DAP

Yield Parameters

Number of capitula per plant: Showed significant variation among treatments due to different levels of RDF and foliar application of nano DAP. The treatment (T_1), that received 100% RDF + foliar spray of nano DAP at 2 ml l^{-1} at 30 and 45 DAS recorded the highest number of capitula per plant (36.45) which was statistically on par with the treatment (T_2), which received 75% RDF plus foliar spray nano DAP at 2 ml l^{-1} at 30 and 45 DAS (34.28). In contrast, the lowest number of capitula per plant (16.90) was recorded in the treatment (T_9), which received only a foliar spray of nano DAP at 4 ml l^{-1} at 30 DAS. (Table 2).

The increase in capitula per plant can be attributed to the foliar application of nano DAP, which improves photosynthetic efficiency and supports the movement of photosynthates from source to sink. This effect is strengthened by a consistent nitrogen supply that promotes capitulum initiation and development. Combining nano DAP with conventional fertilizers proved effective in boosting nutrient availability and uptake, resulting in more capitula per plant. Similar findings were reported by Prasad *et al.* (2012), Manjili *et al.* (2014) and Afify *et al.* (2019) [1, 12, 17].

Number of seeds per capitulum

The number of seeds per capitulum showed significant variation among the different treatments, with different levels of RDF and foliar application of nano DAP (Table 2). The treatment (T_1), that received 100% RDF + foliar spray of nano DAP @ 2 ml l^{-1} at 30 and 45 DAS recorded the highest number of seeds per capitulum (45.95), followed by the treatment with 75% RDF + foliar spray of nano DAP @ 2 ml l^{-1} at the same intervals (43.86). In contrast, the lowest number of seeds per capitulum (24.16) was observed in the treatment which received only a foliar spray of nano DAP @ 4 ml l^{-1} at 30 DAS.

Seed weight per plant (g): The application of 100% RDF as a basal dose combined with a foliar spray of nano DAP @ 2 ml l^{-1} at 30 and 45 DAS resulted in the significantly higher seed weight per plant (43.64 g), which was found statistically on par with the treatment that received 75% RDF plus foliar spray of nano DAP @ 2 ml l^{-1} at the same intervals (42.22 g). In contrast, the lowest seed weight per plant (22.14 g) was recorded in the treatment which received only a foliar spray of nano DAP @ 4 ml l^{-1} at 30 and 45 DAS. (Table 2).

Foliar application of nano DAP helps to increase nutrient efficiency on a nanometer scale in the form of nanoparticles. The particle size of liquid nano fertilizer is smaller than 30 nanometers. Due to its super tiny size and surface qualities, it has around 10,000 times more surface area to volume size, allowing for easier penetration into leaves and conversion into photosynthates, resulting in increased yield contributing characteristics and yield. The present study results agree with the findings of Chaudhary *et al.* (2021) and Pandao *et al.* (2021) [3, 16].

Yield

Seed yield (kg ha^{-1})

The treatment that received 100% RDF + foliar spray of nano DAP at 2 ml l^{-1} at 30 and 45 DAS produced the highest seed yield (1675 kg ha^{-1}) as compared to other treatments and recorded 18.63% increase in yield as compared to treatment that received only RDF. These results were statistically comparable to the treatment with 75% RDF + nano DAP at the same rate and intervals (1589 kg ha^{-1}). In contrast, the lowest seed yield (595 kg ha^{-1}) was recorded in the treatment that received only a foliar spray of nano DAP at 4 ml l^{-1} at 30 DAS. (Table 3).

The higher yield with 100% RDF plus nano DAP is attributed to the combined effect of soil-applied nutrients with foliar-applied nano nitrogen and phosphorus, which together enhanced nutrient uptake and use efficiency. The timely application of nano nutrients during key growth stages ensured a steady supply of nitrogen and phosphorus, which supported leaf development, photosynthetic activity and dry matter accumulation. In addition, the foliar spray of nano DAP extended the photosynthetic period by maintaining healthy leaves and delaying senescence. These combined effects led to a higher overall yield. Similar results were reported by Drostkar *et al.* (2016), Korishettar (2016), Mahdieh *et al.* (2018), and Gondi (2018) [4, 6, 8, 10].

Stover yield (kg ha^{-1})

The application of 100% RDF + foliar spray of nano DAP at 2 ml l^{-1} at 30 and 45 DAS resulted in a significantly higher stover yield (3210 kg ha^{-1}) compared to other treatments except for the treatment (T_2), with 75% RDF + foliar spray of nano DAP at the same rate and timings which produced a comparable yield (3145 kg ha^{-1}). The lowest stover yield (1585 kg ha^{-1}) was recorded in the treatment which received only a foliar spray of nano DAP at 4 ml l^{-1} at 30 DAS. (Table 3).

The increased stover yield with RDF plus nano DAP is mainly due to the improved supply of nitrogen and phosphorus, which enhanced vegetative growth and photosynthetic activity, resulting in greater dry matter production. Using nano-scale nitrogen and phosphorus offers clear advantages over conventional fertilizers because the smaller particles and larger surface area improve nutrient absorption efficiency. Better nutrient uptake supports stronger vegetative growth and higher biomass production. Similar results were reported by Akshay (2021), Hena *et al.* (2022) and Naveen *et al.* (2022) [2, 7, 15].

Harvest index (%)

There was no significant effect on harvest index as influenced by different levels of RDF and foliar application of nano DAP. However, the treatment with 100% RDF as a basal dose combined with a foliar spray of nano DAP at 2 ml l^{-1} at 30 and 45 DAS recorded the highest harvest index (34.28%), while the lowest (27.29%) was observed in the treatment that received only a foliar spray of nano DAP at 2 ml l^{-1} at 30 DAS. (Table 3).

Table 2: Yield parameters of safflower as influenced by different levels RDF and foliar application of nano DAP

Treatment	Number of capitulum per plant	Number of seeds per capitulum	Seed weight per plant (g)
T_1	36.45	45.95	43.64
T_2	34.28	43.86	42.22
T_3	24.67	32.02	30.50
T_4	31.45	40.56	39.10
T_5	30.43	39.68	38.10
T_6	21.90	28.75	27.02
T_7	27.12	35.60	34.52
T_8	28.00	36.00	35.00
T_9	16.90	24.16	22.14
S.Em. ±	0.79	1.04	1.01
C.D. (P=0.05)	2.37	3.10	3.03

Note: RDF- Recommended doses of fertilizers (40: 40: 12.5 - N: P_2O_5: K_2O kg ha^{-1}), DAP- Di-ammonium Phosphate, DAS- Days after sowing

Table 3: Seed yield, Stover yield and Harvest index of safflower as influenced by different levels of RDF and foliar application of nano DAP

Treatments	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)
T_1	1675	3210	34.28
T_2	1589	3145	33.57
T_3	887	2116	29.54
T_4	1470	2919	33.49
T_5	1455	2899	33.42
T_6	758	1855	29.01
T_7	1412	2784	33.65
T_8	1432	2774	34.05
T_9	595	1585	27.29
S.Em. ±	30.17	65.35	1.82
C.D. (P=0.05)	90.46	195.94	NS

Note: RDF- Recommended doses of fertilizers (40: 40: 12.5 - N: P_2O_5: K_2O kg ha^{-1}), DAP- Di-ammonium Phosphate, DAS- Days after sowing

Conclusion

Application of 100% RDF + foliar spray of nano DAP @ 2 ml l^{-1} at 30 and 45 DAS was recorded higher growth parameters and yield parameters, in safflower which was on par with the treatment that received 75% RDF + foliar spray of nano DAP @ 2 ml l^{-1} at 30 and 45 DAS. Further, lower growth parameters, seed yield and stover yield was recorded in the treatment which received only a foliar spray of nano DAP at 4 ml l^{-1} at 30 DAS.

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