



RESEARCH ARTICLE

Growth, yield and quality of tomato (*Solanum lycopersicum* L.) as influenced by foliar sprays of nano-DAP fertilisers

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Abstract

This field study, conducted at the Agricultural Research Station, Chhatabara, during the 2024–25 winter season, tested the hypothesis that foliar nano-DAP sprays (formulations 8:16:0 and 2:5:0) at varying concentrations, combined with reduced nitrogen and phosphorus (P) fertilisers, could enhance tomato (cv. Utkal Pallavi) growth, yield and quality compared to standard practices. Ten treatments featured nano diammonium phosphate (DAP) at different doses alongside 100 % recommended fertiliser [125 kg nitrogen (N), 50 kg phosphate (P_2O_5), 100 kg potash (K_2O) ha^{-1} or 75 % N/P_2O_5 with full K, plus uniform farm yard manure (FYM) at 10 t ha^{-1} . The top performer, T10 [75 % recommended dose of nitrogen and phosphorus (RDNP) + 100 % potassium (K) + nano-DAP 2:5:0 at 5 mL L^{-1}], delivered superior plant height (PH) (57.57 cm), stem girth (SG) (4.27 cm), fruits/plant (54.80), yield/plant (1.83 kg), fruit weight (55.73 g), total yield (325.15 q ha^{-1}) and total soluble solids (TSS) (4.87° Brix)-a 14.66 % yield gain over the control [T₂ (75 % recommended dose of fertilisers (RDF)]. Additional benefits included earlier flowering at 26 DAS in T₉ (75 % RDNP + 100 % K + nano-DAP 2:5:0 at 4 mL L^{-1}), elevated ascorbic acid (22.40 mg g^{-1}) and improved soil nutrient levels. Nano-DAP (2:5:0) at 5 mL L^{-1} , combined with 75 % RDNP and full K, offers a novel, efficient strategy for sustainable tomato production with strong economic gains.

Keywords: foliar spray; nano-DAP; quality parameters; tomato; yield attributes

Introduction

Tomatoes are a nutritional powerhouse and a staple of the Mediterranean diet, offering significant health advantages due to their rich composition (1). They contain essential nutrients like vitamins (C and E), minerals, fiber, protein and amino acids (2, 3). These support crucial body functions, including blood pressure regulation, circulation, detoxification and maintaining bone structure (1, 4, 5). The most notable health benefits come from their high concentration of bioactive antioxidant compounds (6, 7). Key players are carotenoids (primarily lycopene, responsible for the red color), vitamin C and E and phenolic compounds (8, 9). These substances function by scavenging free radicals and inhibiting reactive oxygen species (ROS), thereby protecting cells (8, 10). Lycopene and other phenolics are linked to a wide range of pharmacological effects, including anticancer, anti-inflammatory, antidiabetic and cardioprotective activities (11, 12). Furthermore, the abundant dietary fiber helps manage bowel disorders, diabetes and obesity (13, 14). Overall, the combined nutrients and antioxidants in tomatoes make them a vital food for preventing chronic degenerative diseases and promoting a balanced diet.

Nanotechnology has profoundly transformed contemporary science, with its applications gaining increasing relevance in recent times. A key challenge today is to deliver "sustainable and smart" solutions to enhance agricultural productivity. The integration of

technology enables farmers to optimise the use of water, fertilisers and other inputs, thereby advancing precision farming within the framework of sustainable agriculture while also minimising energy use and waste generation.

Nano diammonium phosphate is an innovative fertiliser technology that employs nanotechnology to improve nutrient delivery efficiency in agriculture. Compared to traditional DAP, nano-DAP supplies crucial nutrients, notably nitrogen (N) and phosphorus (P), in nano-sized particles, thereby enhancing their availability and absorption by plants (15). Smaller particle dimensions increase surface area, enabling faster nutrient uptake and significantly reducing losses from leaching and volatilisation (16).

Nano-fertilisers significantly outperform traditional fertilisers like DAP because their nano-sized particles vastly increase surface area, leading to much better nutrient uptake by plants and dramatically reducing fertiliser waste and required quantities, which in turn cuts input costs. Beyond efficiency, this approach is more environmentally responsible: it minimises chemical runoff to reduce soil and water contamination, lowers energy consumption in both production and application and supports beneficial soil microbes to maintain long-term soil fertility. By enabling targeted nutrient delivery, nano-fertilisers are also essential tools for modern precision farming and promote superior root development, healthier plant growth and better overall crop yields.

Materials and Methods

The field experiment was carried out during October 2024–March 2025 at the Agricultural Research Station, Chhatabaraa, Faculty of Agricultural Sciences, Siksha 'O' Anusandhan, Bhubaneswar, Odisha, India.

The variety Utkal Pallavi is a determinate type, with curly leaves. Fruit-borne in clusters consisting of 6–12 in number. Medium to small in size, pear-shaped, nipple at blossom end and fleshy. Matures in 85–90 days after sowing (DAS). Resistant to bacterial and nematode wilt. It also performs well in saline soil. The average yield is 375.75 quintal ha⁻¹ (17).

The field trial was conducted in a randomised block design (RBD) with 10 treatments and 3 replications. Each plot had dimensions of 3.0 × 2.7 m, with spacing maintained at 60 cm between rows and 45 cm between plants. In each plot, five rows were arranged, each consisting of nine plants, ensuring a proper plant population. To facilitate irrigation, a 90 cm wide channel was provided. The net experimental area covered 243 m², whereas the gross area extended to 297 m². The crop was supplied with the recommended fertiliser dose of 125 kg N, 50 kg phosphate (P₂O₅) and 100 kg potash (K₂O) per hectare. Among the treatments, nano-DAP formulations from two different companies were tested. The IFFCO nano-DAP, produced by the Indian Farmers Fertiliser Cooperative Limited, is a liquid formulation containing 8.0 % N (N w/v) and 16.0 % P₂O₅ (w/v), designed to supplement nutrient requirements and correct N and P deficiencies in crops. Similarly, the gromor Nano-DAP, manufactured by coromandel fertilisers, is a nanoparticle-based liquid fertiliser that provides 2 % N and 5 % P₂O₅ as primary nutrients, thereby serving as another source of N and P for crop growth.

Treatment details

T₁: 100 % RDF (no Nano-DAP fertiliser spray)

T₂: 75 % RDF

T₃: T₂ + Nano-DAP (8:16:0) foliar spray at 2 mL L⁻¹

T₄: T₂ + Nano-DAP (8:16:0) foliar spray at 3 mL L⁻¹

T₅: T₂ + Nano-DAP (8:16:0) foliar spray at 4 mL L⁻¹

T₆: T₂ + Nano-DAP (8:16:0) foliar spray at 5 mL L⁻¹

T₇: T₂ + Nano-DAP (2:5:0) foliar spray at 2 mL L⁻¹

T₈: T₂ + Nano-DAP (2:5:0) foliar spray at 3 mL L⁻¹

T₉: T₂ + Nano-DAP (2:5:0) foliar spray at 4 mL L⁻¹

T₁₀: T₂ + Nano-DAP (2:5:0) foliar spray at 5 mL L⁻¹

NB: 100 % K was applied in all the treatments.

Details of cultural operations

Seed sowing in the nursery

The nursery bed was prepared by thoroughly tilling the soil to a fine tilth and incorporating well-decomposed farmyard manure at a rate of 5 kg m⁻². Raised beds 1 m wide and 15–20 cm high were built to ensure proper drainage. The seeds were treated with saaf (2 g L⁻¹ of water), sprayed at 10–15-day intervals, to prevent seed-borne diseases. Sowing was carried out on 28th October 2024, in shallow furrows spaced 6–8 cm apart and the seeds were lightly covered with fine soil. Immediately after sowing, light irrigation was provided and the beds were mulched with dry grass to maintain moisture and promote uniform germination. Regular care and irrigation were carried out to support healthy seedling growth.

Cultural practices

The experimental plot for tomato cultivation was prepared by ploughing three times, followed by laddering and levelling to break clods. Organic manure (FYM at 8 t ha⁻¹) was applied, along with basal inorganic fertilisers [Urea at 75 or 100 %, single super phosphate (SSP) 100 %, muriate of potash (MOP) 100 %]; top dressing occurred 30 DAS, accompanied by the first foliar spray of IFFCO and gromor nano-DAP and a second spray at 45 days. Healthy 30-day-old seedlings were transplanted on 28 November 2024, at 60 × 30 cm spacing into 2.7 × 3.0 m plots (45 plants each), with immediate light irrigation. Intercultural operations, including hoeing, weeding, earthing up and the first top dressing, were carried out at 30 DAS, with manual weed removal. Irrigation started lightly post-sowing, continued every 2–3 days through pipe irrigation based on soil moisture and followed top dressing. Harvesting began 106 DAS at the marketable maturity stage.

Biometric observations

For recording biometric observations, five randomly selected plants from each subplot, excluding border plants, were used to document growth and yield parameters such as plant height (PH), number of branches per plant (NBPP), stem girth (SG), fruit yield (FY), fruit length (FL), fruit girth (FG) and number of seeds per fruit (NSPF). The height of each selected plant was measured in centimetres from the soil surface to the highest growing point and the average value was recorded. Stem girth was determined by wrapping a thread around the base of each plant, measuring its length with a meter scale and computing the mean value. The number of primary branches was counted for each of the five selected plants to obtain the average NBPP. Plant spread was measured in both east-west and north-south directions using a measuring tape, from the outermost leaf tip on one side to the opposite side, ensuring the plants were not damaged. The average spread in both directions was then calculated separately. The number of days from sowing to first flowering, 50 % flowering, first fruit set, first harvest and peak harvest were recorded to assess the crop's growth and reproductive stages.

Post-harvest observations

To record post-harvest observations, various yield and fruit-quality parameters were measured on the harvested plants within each subplot. Fruit count per plant was determined by counting all the fruits harvested from each sample plant, which were kept separately and the mean value was calculated to represent the average fruit number per plant. The FY per plant was obtained by weighing the total fruits harvested from each marked sample plant within a subplot using a digital balance and the average yield was computed. To determine the average fruit weight, ten fruits were randomly selected from each plot after harvest, weighed individually on a weighing balance and the mean was recorded. The fruit length of ten randomly chosen fruits per subplot was measured in centimetres with the help of a measuring scale and the average was calculated. Similarly, the FG was determined by wrapping a thread around the middle of ten randomly selected fruits from each subplot, marking the intersection and measuring the thread length with a scale to obtain the mean fruit circumference. The FY per plot was recorded after each harvest by weighing all fruits collected from each plot with a digital balance and recording the cumulative yield. For seeds per fruit, five freshly harvested fruits were randomly collected from each plot; the number of seeds per fruit was counted manually and the mean was calculated. The 100-seed weight was determined by randomly selecting 100 clean, air-dried seeds from each treatment,

weighing them on a digital balance and recording the total weight in grams.

Biochemical parameters

The biochemical parameters evaluated included total soluble solids (TSS, expressed as °Brix), soil and plant analyser development (SPAD) value (chlorophyll content) and ascorbic acid content. Total soluble solids was determined by collecting fresh fruits from each of ten treatments at harvest, crushing them separately with a mortar and pestle and analysing the extracted juice using a digital refractometer. Soil and plant analyser development values were measured non-destructively on fully expanded healthy leaves from 5 plants per subplot with a SPAD meter (sensor placed on the middle leaf blade, avoiding the midrib); means were expressed in SPAD units. Ascorbic acid content was quantified by extracting 5 g fresh tomato tissue in 3 % metaphosphoric acid, titrating the filtrate against 2,6-dichlorophenol indophenol (DCPIP) to a light pink endpoint and calculating concentrations via standard curve (expressed as mg 100 g⁻¹ fresh weight) (18, 19).

Results and Discussion

Effect of nano-DAP on vegetative growth of tomato

Plant height

The maximum PH (57.57 cm) was recorded under treatment T₁₀ (75 % RDNP + 100 % K + Gromor nano-DAP at 5 mL L⁻¹ as a foliar spray). This treatment was found not significantly different from T₅ [75 % RDNP + 100 % K + Indian Farmers Fertiliser Cooperative Limited (IFFCO) Nano-DAP at 4 mL L⁻¹], T₉ (75 % RDNP + 100 % K + gromor Nano-DAP at 4 mL L⁻¹), T₄ (75 % RDNP + 100 % K + IFFCO nano-DAP at 3 mL L⁻¹), T₈ (75 % RDNP + 100 % K + gromor nano-DAP at 3 mL L⁻¹) and T₁ (Recommended dose of fertilisers), but it was significantly superior to T₇ (75 % RDNP + 100 % K + Gromor Nano-DAP at 2 mL L⁻¹), T₃ (75 % RDNP + 100 % K + IFFCO nano-DAP at 2 mL L⁻¹) and T₂ (100 % K + 75 % RDNP). The increased PH in T₁₀ due to the enhanced nutrient availability and efficient uptake through foliar application of nano-DAP, leading to better vegetative growth (Table 1) (20, 21).

Stem girth

The maximum SG (4.27 cm) was recorded in T₁₀, which was significantly higher than T₆ (3.87 cm) and T₂ (3.73 cm), but statistically at par with T₉, T₁, T₄, T₅, T₈, T₃ and T₇ (Table 1). The improvement in SG due to the higher nano-DAP concentration, which could have enhanced photosynthetic activity and assimilate translocation, resulting in a thicker stem. A gradual increase in SG was observed with increasing concentration of gromor nano-DAP up to 5 mL L⁻¹. The lowest SG was observed in T₂ (3.73 cm) (Table 1).

Branches per plant

A reference to Table 1 indicates that the maximum branches per plant was observed in T₁ (7.27), which was at par with T₅, T₁₀, T₉, T₄, T₆ and T₇ but significantly better than T₈ (6.73), T₃ (6.47) and T₂ (6.33). The higher number of branches in these treatments is due to balanced nutrient supply and improved plant vigour resulting from nano-DAP application (22–24).

Plant spread (East-west)

The maximum plant spread in the east-west direction (58.70 cm) was recorded in T₈ (75 % RDNP + 100 % K + gromor nano-DAP at 3 mL L⁻¹). This treatment was significantly superior to T₄, T₅ and T₆, but statistically at par with T₁, T₃, T₉, T₂, T₇ and T₁₀ (Table 1). The wider plant spread could be due to enhanced vegetative growth resulting from efficient nutrient utilisation through nano-DAP.

Plant spread (North-south)

The maximum plant spread in the north-south direction (53.17 cm) was observed in T₁ (Recommended dose of fertilisers) and was statistically comparable to all other treatments (Table 1).

Effect of nano-DAP on phenological characters of tomato

Days to first flowering

The minimum number of days to first flowering (26 DAS) was recorded in T₉ (75 % RDNP + 100 % K + Gromor nano-DAP at 4 mL L⁻¹ as foliar spray), while delayed flowering was observed in T₃ (36.33 DAS), T₂ (34.67 DAS), T₅ (34 DAS) and T₈ (33 DAS). However, all the treatments were found to be statistically equivalent. The earlier flowering in gromor nano-DAP treatments might be attributed to enhanced availability and uptake of N and P, thereby promoting rapid vegetative growth and early floral initiation (Table 2).

Table 1. Effect of nano-fertiliser on vegetative growth of tomato

Treatments	Plant height (cm)	Branches per plant	Stem girth (cm)	Plant spread (E-W)	Plant spread (N-S)
T ₁ 100 % RDF (No nano-DAP fertiliser spray)	53.50	7.27	4.20	56.07	53.17
T ₂ 75 % RDNP	48.27	6.33	3.73	54.13	49.16
T ₃ T ₂ + Nano-DAP (8:16:0) foliar spray at 2 mL L ⁻¹	50.93	6.47	3.93	55.17	52.50
T ₄ T ₂ + Nano-DAP (8:16:0) foliar spray at 3 mL L ⁻¹	55.23	6.80	4.13	51.43	52.67
T ₅ T ₂ + Nano-DAP (8:16:0) foliar spray at 4 mL L ⁻¹	56.33	7.00	4.00	51.17	52.57
T ₆ T ₂ + Nano-DAP (8:16:0) foliar spray at 5 mL L ⁻¹	54.20	6.80	3.87	51.17	52.14
T ₇ T ₂ + Nano-DAP (2:5:0) foliar spray at 2 mL L ⁻¹	51.70	6.50	3.93	53.53	51.41
T ₈ T ₂ + Nano-DAP (2:5:0) foliar spray at 3 mL L ⁻¹	54.73	6.73	4.00	58.70	51.91
T ₉ T ₂ + Nano-DAP (2:5:0) foliar spray at 4 mL L ⁻¹	55.43	6.83	4.23	54.77	52.33
T ₁₀ T ₂ + Nano-DAP (2:5:0) foliar spray at 5 mL L ⁻¹	57.57	6.87	4.27	53.40	52.28
SE (m)	1.38	0.18	0.12	2.12	1.86
CV (%)	2.56	2.66	2.98	3.93	3.58

SE (m): Standard error (mean); CV (%): Coefficient of variation.

Table 2. Effect of nano-fertilisers on yield and attributing characters of tomato

Treatments		Days to 1 st flowering	Days to 50 % flowering	Days to 1 st fruit set	Days to 1 st harvest	Days to peak harvest
T ₁	100 % RDF (No Nano-DAP fertiliser spray)	32.00	52.33	45.67	77.00	95.67
T ₂	75 % RDNP	34.67	51.67	45.00	76.00	94.00
T ₃	T ₂ + Nano-DAP (8:16:0) foliar spray at 2 mL L ⁻¹	36.33	58.33	47.00	78.33	98.00
T ₄	T ₂ + Nano-DAP (8:16:0) foliar spray at 3 mL L ⁻¹	28.33	51.00	46.33	76.00	96.33
T ₅	T ₂ + Nano-DAP (8:16:0) foliar spray at 4 mL L ⁻¹	34.00	56.33	48.33	79.00	95.67
T ₆	T ₂ + Nano-DAP (8:16:0) foliar spray at 5 mL L ⁻¹	31.00	53.33	47.33	80.00	95.67
T ₇	T ₂ + Nano-DAP (2:5:0) foliar spray at 2 mL L ⁻¹	31.00	55.33	45.00	78.00	95.67
T ₈	T ₂ + Nano-DAP (2:5:0) foliar spray at 3 mL L ⁻¹	33.00	55.33	43.00	77.33	95.67
T ₉	T ₂ + Nano-DAP (2:5:0) foliar spray at 4 mL L ⁻¹	26.00	50.33	47.33	81.00	95.67
T ₁₀	T ₂ + Nano-DAP (2:5:0) foliar spray at 5 mL L ⁻¹	31.67	53.67	51.67	80.00	90.00
SE (m)		2.22	1.91	3.10	1.92	2.14
CV (%)		12.10	6.12	11.60	4.26	3.88

SE (m): Standard error (mean); CV (%): Coefficient of variation.

Days to 50 % flowering

The treatment T₉ (50.33 DAS) recorded the minimum time to 50 % flowering, whereas delayed flowering was observed in T₃ (58.33 DAS) and T₄ (56.33 DAS). Although numerical differences were evident among treatments, all were statistically similar (Table 2).

Days to first fruit set

Data presented in Table 2 show no significant variation among the treatments for days to first fruit set. The earliest fruit set was observed in T₇ (45 DAS) and was statistically comparable to all other treatments. This indicates that the nano-DAP application did not exert a marked influence on the initiation of fruit set in tomato.

Days to first harvest

Treatment T₂ (76 DAS) recorded the earliest fruit harvest, which was not statistically different from those of the remaining treatments. The non-significant difference among treatments suggests that nano-DAP had little effect on the duration of the first picking (Table 2).

Days to peak harvest

Timely attainment of peak harvest is advantageous for growers as it allows early market entry and better prices. The data (Table 2) reveal that treatment T₉ (90 DAS) reached peak harvest the fastest, while T₃ (98 DAS) reached peak harvest the slowest. However, all the treatments were statistically similar. The earlier peak harvest in nano-DAP treated plots is due to improved nutrient assimilation, resulting in synchronised flowering and fruiting.

Nano-DAP on the yield and attributing characters of tomato

Fruit length

The maximum fruit length (5.70 cm) was recorded in T₄ (75 % RDNP + 100 % K + IFFCO nano-DAP at 3 mL L⁻¹ as a foliar spray), which was nearly the same as that of all other treatments (23) (Table 3).

Fruit width

The highest fruit width (5.53 cm) was observed in T₂ (100 % K) and was statistically comparable to the other treatments. This suggests that nano-DAP treatments did not significantly affect fruit width among the evaluated treatments (Table 3).

Seeds per fruit

The maximum NSPF (97.50) was obtained in T₁₀ (75 % RDNP + 100 % K + Gromor nano-DAP at 5 mL L⁻¹), which was significantly higher than T₄ (85.63), T₅ (84.23) and T₆ (83.27), but statistically at par with T₉ (93.83), T₂ (92.30), T₇ (91.30), T₁ (90.70), T₈ (89.13) and T₃ (88.17). The

increased NSPF at higher nano-DAP concentrations might be attributed to improved nutrient uptake and enhanced reproductive growth (25–27) (Table 3).

Fruit yield per plant

The maximum FY per plant (1.83 kg) was obtained with T₁₀ (75 % RDNP + 100 % K + Gromor nano-DAP at 5 mL L⁻¹), which was statistically at par with T₁, T₂ and T₆, but significantly superior to the remaining treatments. The lowest yield per plant was recorded in T₇ and was statistically comparable to T₈ and T₉. The enhanced yield in T₁₀, due to increased assimilate accumulation and efficient nutrient utilisation, was facilitated by the application of nano-DAP (25, 26) (Table 3).

Fruit weight

The maximum fruit weight (55.73 g) was recorded in T₁₀, which was statistically at par with T₉ (50.67 g), T₆ (50.33 g), T₅ (49.47 g) and T₁ (47.23 g), but significantly higher than T₄, T₈, T₃, T₇ and T₂ (36.70 g) (Table 3). The increased fruit weight under higher nano-DAP concentrations may be due to improved nutrient absorption and greater assimilate accumulation in fruits (23, 24).

100-Seed weight

The highest 100-seed weight (0.50 g) was recorded in T₆ (75 % RDNP + 100 % K + IFFCO nano-DAP at 5 mL L⁻¹), which was statistically at par with T₅ (0.47 g) and T₄ (0.46 g) and significantly superior to T₁ (0.41 g), T₈ (0.41 g), T₉ (0.40 g), T₃ (0.40 g), T₂ (0.39 g), T₁₀ (0.39 g) and T₇ (0.38 g). The increase in seed weight under T₆ might be due to adequate nutrient supply and enhanced seed filling. (Table 3).

Fruit yield

The maximum FY (325.15 q ha⁻¹) was recorded in T₁₀ (75 % RDNP + 100 % K + Gromor nano-DAP at 5 mL L⁻¹), which was significantly higher than T₈ (283.8 q ha⁻¹), T₂ (283.5 q ha⁻¹), T₄ (283.2 q ha⁻¹), T₃ (279.7 q ha⁻¹), T₇ (270.6 q ha⁻¹) and T₆ (267.1 q ha⁻¹) and at par with T₁ (306.4 q ha⁻¹), T₅ (293.6 q ha⁻¹) and T₉ (291.2 q ha⁻¹). The increased FY at higher nano-DAP concentrations is due to improved nutrient use efficiency (Table 3).

Effect of nano-DAP on biochemical parameters of tomato

Biochemical parameters

Fruit TSS (*Brix): The treatment T₁₀ (4.87) was at par with T₄ (4.87), T₇ (4.48) and T₆ (4.31) but significantly superior to the treatments T₅ (4.18), T₈ (4.09), T₂ (3.97), T₉ (3.93), T₁ (3.92) and T₃ (3.71) (22, 24) (Table 4).

Table 3. Effect of nano-fertilisers on yield and attributing characters of tomato

Treatments		Fruit length (cm)	Fruit width (cm)	Fruits per plant	Fruit weight (g)	Seeds per fruit	100 seed weight (g)	Fruit yield per plant (kg)	Fruit yield (q ha ⁻¹)
T ₁	100 % RDF (Control) (No nano-DAP fertiliser spray)	5.57	4.83	50.47	47.23	90.70	0.41	1.64	306.4
T ₂	75 % RDNP	5.17	4.53	47.50	36.70	89.97	0.39	1.63	283.57
T ₃	T ₂ + Nano-DAP (8:16:0) foliar spray at 2 mL L ⁻¹	5.47	5.04	47.67	41.70	88.17	0.40	1.49	279.74
T ₄	T ₂ + Nano-DAP (8:16:0) foliar spray at 3 mL L ⁻¹	5.70	5.39	48.43	44.40	85.63	0.46	1.53	283.2
T ₅	T ₂ + Nano-DAP (8:16:0) foliar spray at 4 mL L ⁻¹	5.60	5.51	49.63	49.47	84.23	0.47	1.58	293.69
T ₆	T ₂ + Nano-DAP (8:16:0) foliar spray at 5 mL L ⁻¹	5.60	4.72	54.17	50.33	83.27	0.50	1.82	267.16
T ₇	T ₂ + Nano-DAP (2:5:0) foliar spray at 2 mL L ⁻¹	5.33	4.77	44.07	40.17	91.30	0.38	1.25	270.61
T ₈	T ₂ + Nano-DAP (2:5:0) foliar spray at 3 mL L ⁻¹	5.40	5.04	45.03	43.70	92.07	0.41	1.41	283.82
T ₉	T ₂ + Nano-DAP (2:5:0) foliar spray at 4 mL L ⁻¹	5.57	5.19	47.03	50.67	93.83	0.40	1.42	291.22
T ₁₀	T ₂ + Nano-DAP (2:5:0) foliar spray at 5 mL L ⁻¹	5.67	5.23	54.80	55.73	97.50	0.39	1.83	325.15
	SE (m)	0.26	0.33	3.15	3.25	2.82	0.02	0.08	12.34
	CV (%)	8.17	11.45	11.25	12.08	5.48	8.25	8.97	7.41

SE (m): Standard error (mean); CV (%): Coefficient of variation.

Fruit ascorbic acid: The maximum ascorbic acid was recorded in treatments T₉ (22.40 mg g⁻¹) and T₁₀ (22.40 mg g⁻¹), which were significantly higher than the remaining treatments (27, 28) (Table 4).

Spad value for leaf chlorophyll: The maximum SPAD value was observed in treatment T₅ (53.73), which was significantly better than T₉ (44.27) and T₁₀ (43.87) but was at par with the rest of the treatments (26, 28) (Table 4).

Soil parameters

pH

The highest pH value (6.86) was observed in T₉, which was followed by T₇ and T₃. The lowest pH (6.41) was recorded in T₁ (Table 5).

Electrical conductivity

The maximum EC value (0.70 dS m⁻¹) was recorded in T₈, followed by T₄ (Table 5). The minimum EC was recorded by T₇ (0.31 dS m⁻¹).

Organic carbon

The highest soil organic carbon (9.98 g kg⁻¹) was recorded in T₄, followed by T₆ and T₉. The lowest soil organic carbon was recorded in both T₃ and T₅ (4.17 g kg⁻¹) (Table 5).

Available phosphorus

The highest available P was observed in treatment T₆ (29.1 g kg⁻¹), followed by T₈ and T₁₀ (Table 5). Both T₅ and T₇ have recorded the lowest available soil P content, i.e., 24.4 kg ha⁻¹ (Table 5).

Available potassium

The maximum available soil potassium content was observed in treatment T₆ (467 kg ha⁻¹), which was followed by T₄ and T₁₀ and the minimum available soil potassium content was observed in T₅ (311 kg ha⁻¹) (Table 5).

Economics

The treatment T₁₀ was best in terms of gross income (Rs 4,87,725), net income (₹202808) and benefit: cost (B:C) ratio (1.7). The minimum B:C ratio was observed in T₆ (1.3). The maximum and minimum cultivation costs were observed in T₆ (₹289776) and T₂ (₹271791), respectively (Table 6).

Table 4. Effect of nano-fertilisers on Biochemical parameters of tomato

Treatments		TSS(°Brix)	Ascorbic acid (mg g ⁻¹)	SPAD value
T ₁	100 % RDF (No nano-DAP fertiliser spray)	3.92	19.80	43.87
T ₂	75 % RDNP	3.97	17.13	43.87
T ₃	T ₂ + Nano-DAP (8:16:0) foliar spray at 2 mL L ⁻¹	3.71	21.10	43.87
T ₄	T ₂ + Nano DAP (8:16:0) foliar spray at 3 mL L ⁻¹	4.51	21.10	43.87
T ₅	T ₂ + Nano-DAP (8:16:0) foliar spray at 4 mL L ⁻¹	4.18	18.43	43.87
T ₆	T ₂ + Nano-DAP (8:16:0) foliar spray at 5 mL L ⁻¹	4.31	21.13	43.87
T ₇	T ₂ + Nano-DAP (2:5:0) foliar spray at 2 mL L ⁻¹	4.48	19.77	43.87
T ₈	T ₂ + Nano-DAP (2:5:0) foliar spray at 3 mL L ⁻¹	4.09	19.80	43.87
T ₉	T ₂ + Nano-DAP (2:5:0) foliar spray at 4 mL L ⁻¹	3.93	22.40	43.87
T ₁₀	T ₂ + Nano-DAP (2:5:0) foliar spray at 5 mL L ⁻¹	4.87	22.40	43.87
	SE (m)	0.22	1.40	3.01
	CV (%)	9.07	11.98	11.87

SE (m): Standard error (mean); CV (%): Coefficient of variation.

Table 5. Analysis of final soil samples

Treatments	pH	Electrical conductivity (dS m ⁻¹)	Organic carbon (g kg ⁻¹ soil)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)
T ₁ 100 % RDF (No nano-DAP fertiliser spray)	6.41	0.67	6.34	28.4	432.0
T ₂ 75 % RDNP	6.45	0.40	5.62	27.7	324.0
T ₃ T ₂ + Nano-DAP (8:16:0) foliar spray at 2 mL L ⁻¹	6.81	0.44	4.17	25.7	333.0
T ₄ T ₂ + Nano-DAP (8:16:0) foliar spray at 3 mL L ⁻¹	6.58	0.60	9.98	25.1	422.0
T ₅ T ₂ + Nano-DAP (8:16:0) foliar spray at 4 mL L ⁻¹	6.56	0.51	4.17	24.4	311.0
T ₆ T ₂ + Nano-DAP (8:16:0) foliar spray at 5 mL L ⁻¹	6.70	0.70	9.97	29.1	467.0
T ₇ T ₂ + Nano-DAP (2:5:0) foliar spray at 2 mL L ⁻¹	6.82	0.31	4.80	24.4	313.0
T ₈ T ₂ + Nano-DAP (2:5:0) foliar spray at 3 mL L ⁻¹	6.54	0.61	9.07	28.4	420.0
T ₉ T ₂ + Nano-DAP (2:5:0) foliar spray at 4 mL L ⁻¹	6.86	0.44	9.79	27.8	340.0
T ₁₀ T ₂ + Nano-DAP (2:5:0) foliar spray at 5 mL L ⁻¹	6.74	0.52	8.16	28.1	421.0

Table 6. Economics of treatments

Treatments	Yield (q ha ⁻¹)	Gross income (₹ha ⁻¹)	Total cost of cultivation (₹ha ⁻¹)	Net income (₹ha ⁻¹)	B:C ratio
T ₁ 100 % RDF (No nano-DAP fertiliser spray)	306.4	459600	273428	186171	1.6
T ₂ 75 % RDNP	283.57	425355	271791	153563	1.5
T ₃ T ₂ + Nano-DAP (8:16:0) foliar spray at 2 mL L ⁻¹	279.74	419610	285285	134324	1.4
T ₄ T ₂ + Nano-DAP (8:16:0) foliar spray at 3 mL L ⁻¹	283.2	424800	286782	138017	1.4
T ₅ T ₂ + Nano-DAP (8:16:0) foliar spray at 4 mL L ⁻¹	293.69	440535	288289	152245	1.5
T ₆ T ₂ + Nano-DAP (8:16:0) foliar spray at 5 mL L ⁻¹	267.16	400740	289776	110963	1.3
T ₇ T ₂ + Nano-DAP (2:5:0) foliar spray at 2 mL L ⁻¹	270.61	405915	283341	122573	1.4
T ₈ T ₂ + Nano-DAP (2:5:0) foliar spray at 3 mL L ⁻¹	283.82	425730	283866	141863	1.4
T ₉ T ₂ + Nano-DAP (2:5:0) foliar spray at 4 mL L ⁻¹	291.22	436830	284391	152438	1.5
T ₁₀ T ₂ + Nano-DAP (2:5:0) foliar spray at 5 mL L ⁻¹	325.15	487725	284916	202808	1.7

Conclusion

The study revealed that treatment T₁₀ was the most effective among all treatments, recording the highest PH (57.57 cm), SG (4.27 cm), fruit number, fruit weight (55.73 g), FY per plant (1.83 kg), total yield (325.15 q ha⁻¹) and TSS (4.87° Brix). This treatment produced 14.66 % higher yield than the check (T₂) and achieved the highest benefit: cost ratio (1.7), indicating superior economic efficiency. Other treatments showed results, including maximum plant spread in T₈, earliest flowering in T₉, highest SPAD value in T₉ and higher soil organic carbon in T₄. Despite individual differences, T₁₀ consistently outperformed all treatments in both growth and yield parameters. Moreover, it reduced the use of conventional fertilisers by 25 %, enhanced soil fertility and improved overall crop productivity and quality, proving to be the most sustainable and profitable nutrient management approach under the study conditions.

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Authors' contributions

SP and AN planned the study and designed the experiments. SP and PJ conducted data collection, field and laboratory experiments, data analysis, result interpretation and drafted the initial manuscript. SP, ND and PJ performed the literature review and edited the manuscript. All authors read and approved the final manuscript.

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During the preparation of this work, the authors used Grammarly in order to check grammar. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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