

Split application of nano urea and conventional urea for optimizing nitrogen management in chrysanthemum under polyhouse conditions

Shikha Rana

shikharana23hmr@gmail.com

Dr. Yashwant Singh Parmar University of Horticulture and Forestry

S R Dhiman

Dr. Yashwant Singh Parmar University of Horticulture and Forestry

Puja Sharma

Dr. Yashwant Singh Parmar University of Horticulture and Forestry

Upender Singh

Dr. Yashwant Singh Parmar University of Horticulture and Forestry

Anju Sharma

Dr. Yashwant Singh Parmar University of Horticulture and Forestry

Research Article

Keywords: Chrysanthemum, Split nitrogen application, Nitrogen use efficiency, Flowering and yield attributes, Sustainable nutrient management

Posted Date: May 12th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-9445022/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Synthetic fertilizers have played a pivotal role in enhancing crop productivity and quality; however, excessive dependence on conventional fertilizers, particularly urea, has led to low nutrient-use efficiency, environmental contamination, soil fertility depletion and associated ecological risks. These challenges have intensified the need for sustainable and climate-resilient nutrient management strategies, especially under protected cultivation systems. Chrysanthemum is a high-value floricultural crop, is a heavy nitrogen feeder and its growth, flowering and yield are strongly influenced by nitrogen availability. Nano urea, owing to its higher foliar absorption efficiency (80%) and controlled nutrient release, has emerged as a promising alternative to conventional urea for improving nitrogen-use efficiency while minimizing nutrient losses. A factorial randomized block design experiment was conducted during 2022–2023 under polyhouse conditions to evaluate the effect of split applications of urea and nano urea on growth, flowering, yield and soil nutrient status of chrysanthemum. Treatments comprised different doses of nano urea and urea applied at weekly, biweekly and fortnightly intervals, starting after pinching and continued up to twelve weeks. Results indicated that nano urea applied at 100 ppm once in a fortnight significantly enhanced plant height (170.49 cm), plant spread (58.90 cm), flowering earliness (138.5 days), flower size (16.23 cm), cut flower yield/plant (6.37) and postharvest longevity (27 days), with improvements of 15–30% over conventional urea treatments. This treatment also resulted in lower residual soil nitrogen, phosphorus and potassium levels, reflecting improved nutrient uptake efficiency and reduced nutrient accumulation. The study highlights nano urea as a sustainable, high-efficiency nitrogen management strategy capable of improving productivity, profitability and resource-use efficiency in chrysanthemum cultivation.

1 Introduction

Chrysanthemum (*Chrysanthemum morifolium* Ramat.), a member of the Asteraceae family, is one of the most commercially important floricultural crops in the world. It is cultivated extensively for its wide-ranging utilities as cut and loose flowers, ornamental pot plants, landscaping resources and in pharmaceutical applications [7, 24, 42]. Globally, chrysanthemum ranks second in the cut flower trade, contributing nearly 9.77% of the market share [39] and significantly bolstering the economic turnover of the floriculture sector [18, 11, 33]. In India, this flower is important source of foreign exchange and rural socio-economic sustenance [43]. With increasing global quality standards and year-round demand, commercial chrysanthemum production is increasingly shifting toward protected cultivation systems such as greenhouses and polyhouses.

Nutrient availability plays a decisive role in chrysanthemum growth and productivity under protected cultivation. Among essential nutrients, nitrogen is of paramount importance, as it forms a core component of nucleic acids, proteins and chlorophyll, directly influencing photosynthesis and plant assimilation [47, 17, 13]. Chrysanthemum is a heavy nitrogen feeder, with optimal leaf nitrogen levels reported between 4.6% and 6.0% [37]. Thus, precise nitrogen management is critical to achieve high yield, desirable ornamental attributes, and reduced production costs [71, 23]. However, the imbalanced

use of conventional urea has emerged as a key factor behind declining productivity and inconsistent flower quality. Global urea consumption rise by 20.9% in a decade (2009–2019), reaching 178.3 million tonnes [62]. Urea production itself is energy-intensive and contributes to 0.93% of global GHG emissions [4, 34, 32]. Moreover, its excessive application reduces nutrient-use efficiency signifying that 50–70% of applied nitrogen is dissipated as atmospheric NO_x emissions or leached into aquatic ecosystems, degrades soil and leads to broader ecological imbalances [8, 70]. In comparison to polyhouse conditions, fertigation with split nitrogen application supplies nutrients precisely to the root zone, enhancing efficiency, reducing leaching losses, lowering production costs and ensuring sustainable regulation of nutrient supply [66].

Nano-fertilizers, particularly nano urea, are emerging as sustainable alternatives to conventional urea. With a nanoscale particle size (30 nm) and a 10,000-fold higher surface area-to-volume ratio, nano urea enables efficient foliar absorption and targeted nitrogen delivery at critical growth stages [27, 36, 45]. A 500 ml bottle of nano urea, containing 4% nitrogen, can replace a 50 kg bag of conventional urea, cutting nitrogen requirements by half while achieving 80% nitrogen-use efficiency compared to 30–40% for granular urea [22, 28, 51, 55]. This reduces fertilizer consumption, improves soil health, lowers environmental risks and increases farmers profitability [61] and in wheat cultivation integration of nano urea significantly improves the cost-benefit ratio, thereby strengthening the economic viability of production systems [29]. Studies further suggest that nano fertilizers enhance plant growth traits, chlorophyll content thereby increased overall productivity [1, 6, 40].

Split application of nitrogen is widely recognized as an effective strategy to synchronize nutrient availability with crop demand, thereby minimizing leaching losses and reducing lodging risks [69]. Despite chrysanthemum's importance as a cut flower crop, limited information is available on the combined use of conventional urea and nano urea in split application regimes under protected conditions. Addressing this gap is essential for improving nitrogen use efficiency improving yield, quality, and mitigating nitrogen-related losses. Therefore, the present investigation was undertaken to evaluate the effects of split applications of urea and nano urea on the growth and flowering of chrysanthemum under polyhouse conditions, with the aim of developing an efficient and sustainable nitrogen management strategy for protected cultivation systems.

2 Materials and methods

2.1 Experimental site and plant material

The field experiment was conducted in the year 2022–2023 at Hi-Tech Floriculture Farm of Department of Floriculture and Landscape Architecture, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (Himachal Pradesh), which is situated at 30°52' latitude North and 77°11' longitude East at an elevation of 1276 m above mean sea level, representing the mid-hill zone of Himachal Pradesh. The maximum rainfall received during the monsoon season (July to September) and the mean monthly meteorological data for the crop growing period have been presented in Fig. 1.

Shoot tip cuttings of two commercial standard type chrysanthemum (*Chrysanthemum morifolium* Ramat.) cvs namely, 'White Star' (Fig. 2A) and 'Yellow Star' (Fig. 2B) were obtained from the Hi-Tech Floriculture Farm, Department of Floriculture and Landscape Architecture, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India (30°52' N latitude, 77°11' E longitude). The plant material was maintained under protected cultivation conditions and selected from healthy, disease-free mother stock. These cuttings were immersed in a solution of Dithane M-45 (0.2%) and Bavistin (0.1%) for 30 minutes.

After the immersion, the basal leaves were removed and a sharp cut was made just below the basal node. The cut ends were then dipped in a NAA solution (500 ppm) before planting. Once rooted, the cuttings were moved to a shade net house for hardening. After 10 days, they were transplanted, using plots of size 1.0 m × 1.0 m at a spacing of 30 cm × 20 cm, maintain a planting density of 15 plants/m². Before transplanting, composite soil samples (0–15 cm depth) were collected and analysed to determine the initial physico-chemical characteristics (Table 1).

Table 1
Physico-chemical properties of the soil before planting

Sr. No.	Physico-chemical property	Soil fertility	Interpretation	Reference
1	Soil pH	7.73	Normal	[21]
2	Electrical Conductivity (dSm ⁻¹)	0.094	Normal	[21]
3	Organic Carbon (%)	0.67	Medium	[65]
4	Available Nitrogen (kg/ha)	276.8	Medium	[57]
5	Available Phosphorus (kg/ha)	16.95	Medium	[38]
6	Available Potassium (kg/ha)	192.5	Medium	[35]

2.2 Design of experiment and fertilizers

The experimental study used a randomized block design (factorial) with 7 nutritional modules and 3 replications proposed by Gomez and Gomez (1984). NPK were supplied in the form of a 12:32:16 @ 24 g/m² at the time of bed preparation. To meet the recommended nitrogen, phosphorus and potassium levels for chrysanthemum production (30 g/m² each), rest of the nutrients were provided using urea, nano urea, SSP and MOP. Treatments comprised of split application of nitrogen through conventional urea and nano urea were made in such a way that after completing the fertigation schedule each plot received the recommended nitrogen dose i.e., 30 g /T2 as shown in Table 2.

Table 2
Details of nutritional modules of experiment

Nutritional Modules	Application
T ₁	25 ppm nano urea (one litre solution/m ² was sprayed on the plants twice a week, starting after pinching and continued up to twelve weeks).
T ₂	50 ppm nano urea (one litre solution/m ² was sprayed on the plants once a week, starting after pinching and continued up to twelve weeks).
T ₃	100 ppm nano urea (one litre solution/m ² was sprayed on the plants once in fortnight, starting after pinching and continued up to twelve weeks).
T ₄	2500 ppm urea (one litre solution/m ² was drenched equally in the root zones of all fifteen plants twice a week, starting after pinching and continued up to twelve weeks).
T ₅	5000 ppm urea (one litre solution/m ² was drenched equally in the root zones of all fifteen plants once a week, starting after pinching and continued up to twelve weeks).
T ₆	10000 ppm urea (one litre solution/m ² was drenched equally in the root zones of all fifteen plants once in fortnight, starting after pinching and continued up to twelve weeks).
T ₇	30 g/m ² each of NPK was applied as basal dose following standard procedure i.e., fifty percent of nitrogen was applied at the time of bed preparation and remaining fifty percent of nitrogen was supplied after 40 days of planting.

In T₁, 0.31 ml of nano urea was mixed in 1 litre of water to form 25 ppm solution. In T₂, 0.62 ml of nano urea was mixed in 1 litre water to form 50 ppm solution. Similarly, in T₃, 1.25 ml of nano urea was mixed in 1 litre water to form 100 ppm solution. In T₄, 2.5 g urea was dissolved in 1 litre of water (2500 ppm). In T₅, 5 g urea was dissolved in 1 litre of water (5000 ppm). In T₆, 10 g urea was dissolved in 1 litre of water (10000 ppm). In T₇, basal dose 30 g each of NPK was applied in the form of 12:32:16, urea, single super phosphate and muriate of potash.

2.3 Growth and flowering observations

In each replication and treatment, ten plants were randomly tagged and all vegetative as well as flowering parameters were recorded at the relevant stages of data collection. Plant height and plant spread were measured at the time of harvesting of first cut stem. Days to bud initiation and flowering were calculated from transplanting to first visible bud and first floret opening, respectively. Floral diameter was precisely measured using a digital vernier calliper. Vase life was assessed as the interval from placement of cut stems in distilled water to the stage until they remained presentable. From every tagged plant number of cut stems per plant and per square meter were recorded.

2.4 Soil analysis

Soil samples (0-0.15 m depth) were collected before transplanting (Table 1) and after harvesting of cut flower stem of from each treatment and replication. Samples were air-dried and sieved through a 2 mm mesh. The samples were analyzed for soil pH and electrical conductivity (EC) using standard protocols [21]. Organic carbon was estimated by the [65], available nitrogen by the alkaline permanganate method [57], available phosphorus by the [38] and available potassium by the flame photometric method [35].

2.5 Statistical analysis

Statistical analyses were performed using Minitab 21.1.0 (Minitab Inc., State College, PA, USA), applying two-way ANOVA and treatment means were compared through Tukey's post hoc test at 5% significance level. Standard deviations of the data were computed using Microsoft Excel.

3 Results and discussion

3.1 Vegetative parameters

Significant differences in plant height were observed among the treatments across different nutritional modules and cultivars, with values ranging from 117.92 to 170.49 cm (Table 3). The tallest plants were recorded under T3V2 (170.49 cm), followed by T2V2 (163.19 cm) and T3V1 (162.80 cm). In contrast, the shortest plants were observed under T7V1 (117.92 cm), representing a 30.8% reduction in height compared to the maximum value. The increased plant height under nano urea (T2, T3) doses could be attributed that nano fertilizers improve plant nutritional efficiency, lower their toxicity to soil organisms and lower the impacts of potential stress from fertilizers over application [25]. The difference in growth of cultivars may be attributed to their genetic makeup. In contrast, lower plant height observed with the application of urea (T6 and T7) may be due to the sub-optimal nitrogen supply and nitrogen stress, leading to stunted vegetative growth. The present findings aligned with the existing findings of Goud et al. [15] in sunflower, Rawate et al. [49] in wheat and Venkatesh et al. [64] in marigold. They found that foliar application of nano urea increases the plant height because nano urea is easily absorbed by plants.

Table 3
Effect of split application of urea and nano-urea on vegetative parameters of chrysanthemum cvs 'White Star' and 'Yellow Star'

Nutritional modules	Variety	Plant Height	Plant spread	Leaf length	Number of side shoots per plant
T1	V1	144.69 ± 1.55 ^f	48.96 ± 1.81 ^{cd}	13.28 ± 0.36 ^{ab}	5.70 ± 0.36 ^b
T2	V1	158.03 ± 1.15 ^{bc}	56.85 ± 3.36 ^{ab}	13.10 ± 0.48 ^{abc}	6.53 ± 0.23 ^a
T3	V1	162.80 ± 1.76 ^b	58.90 ± 1.03 ^a	13.80 ± 0.77 ^a	6.53 ± 0.12 ^a
T4	V1	154.39 ± 0.69 ^{cd}	55.35 ± 2.12 ^{abc}	13.44 ± 0.15 ^{ab}	5.60 ± 0.17 ^b
T5	V1	144.87 ± 3.24 ^f	50.20 ± 3.18 ^{bcd}	12.54 ± 0.60 ^{abcd}	5.37 ± 0.25 ^{bc}
T6	V1	142.73 ± 1.83 ^f	49.25 ± 0.82 ^{cd}	12.41 ± 0.53 ^{bcd}	5.07 ± 0.15 ^{cd}
T7	V1	117.92 ± 0.43 ^h	44.85 ± 3.03 ^{de}	11.51 ± 0.425 ^d	4.70 ± 0.10 ^{de}
T1	V2	151.92 ± 1.96 ^{de}	46.53 ± 1.56 ^{de}	12.59 ± 0.16 ^{abcd}	3.80 ± 0.10 ^{fg}
T2	V2	163.19 ± 1.49 ^b	53.89 ± 1.64 ^{abc}	12.92 ± 0.15 ^{abc}	3.90 ± 0.20 ^{fg}
T3	V2	170.49 ± 0.59 ^a	56.38 ± 1.91 ^{ab}	12.91 ± 0.07 ^{abc}	4.27 ± 0.06 ^{ef}
T4	V2	154.07 ± 2.82 ^{cd}	50.24 ± 2.33 ^{bcd}	13.28 ± 0.61 ^{ab}	3.67 ± 0.06 ^{G^h}
T5	V2	147.07 ± 1.02 ^{ef}	44.35 ± 3.66 ^{de}	12.43 ± 0.32 ^{bcd}	3.47 ± 0.06 ^{gh}
T6	V2	146.60	43.91	12.09 ± 0.24 ^{bcd}	3.40 ± 0.10 ^{gh}
*T ₁ : 25 ppm nano urea twice in a week; *T ₂ : 50 ppm nano urea once in a week; *T ₃ : 100 ppm nano urea once in fortnight; *T ₄ : 2500 ppm urea twice in a week; *T ₅ : 5000 ppm urea once in a week; *T ₆ : 10000 ppm urea once in fortnight; *T ₇ : Basal dose 30 g each of NPK.					
V1= 'White Star', V2= 'Yellow Star'					
Mean values with same superscripted letters in each column are not significantly different according to Tukey's HSD test at P < 0.05.					

Nutritional modules	Variety	Plant Height	Plant spread	Leaf length	Number of side shoots per plant
		$\pm 2.26^{ef}$	$\pm 2.11^{de}$		
T7	V2	133.10 $\pm 3.63^g$	39.77 $\pm 1.91^e$	11.89 ± 0.70^{cd}	3.17 ± 5.05^h
*T ₁ : 25 ppm nano urea twice in a week; *T ₂ : 50 ppm nano urea once in a week; *T ₃ : 100 ppm nano urea once in fortnight; *T ₄ : 2500 ppm urea twice in a week; *T ₅ : 5000 ppm urea once in a week; *T ₆ : 10000 ppm urea once in fortnight; *T ₇ : Basal dose 30 g each of NPK.					
V1= 'White Star', V2= 'Yellow Star'					
Mean values with same superscripted letters in each column are not significantly different according to Tukey's HSD test at P < 0.05.					

Notable variations were found values ranging from 39.77 cm to 58.90 cm in plant spread among the treatments under various nutritional regimes and cultivars (Table 3). The greatest plant spread was recorded in T3V1 (58.90 cm), T2V1 (56.85 cm) and T3V2 (56.38 cm) respectively. The minimum spread was observed under T7V2 (39.77 cm), which was 32.47% lower than the maximum. The enhanced plant spread observed under nano urea treatments (T2 and T3) can be attributed to the higher nitrogen use efficiency of nano urea (85–90%) compared to conventional urea (30–40%) [22]. Differences in growth among the cultivars may be due to inherent genetic factors. Lower plant spread recorded under urea application (T6 and T7) could be due to the inefficient retention of urea in the soil, leading to reduced uptake by plants. Gayathri et al. [12] in safflower, Soundarya et al. [55] in sunflower and Saud et al. [51] in rice discovered that the application of nano urea resulted in the attainment of maximum plant expansion in crops.

Leaf length exhibited significant variation across treatments under various nutritional modules and cultivars, with recorded values ranging from 11.51 cm to 13.80 cm. (Table 3). The maximum leaf length was attained in T3V1 (13.80 cm), trailed by T4V1 (13.44 cm) and T1V1 (13.28 cm). Conversely, T7V1 exhibited a leaf length that was 16.59% less than the peak value recorded. The increased leaf length under nano urea (T2 and T3) doses because nitrogen is a substantial component of proteins, amino acids, vitamins, hormones and enzymes, which supplied nutrient for leaf development Karthika et al. [26]. The results of longest leaf length with the application of nano urea were found to be in confirmation with the studies of Pandav et al. [41] in mustard and Dhamankar et al. [10] in rice.

The number of lateral shoots per plant exhibited marked variation across the treatments, ranging from 3.17 to 6.53 (Table 3). The greatest number was recorded in T3V1 (6.53), closely followed by T2V1 (6.53) and T1V1 (5.70). The minimum count was noted in T7V2 (3.17), representing a 51.45% reduction relative to the highest value. Nano urea treatments (T2 and T3) resulted in a greater number of lateral shoots per plant, may be attributed to the smaller particle size and higher particle density of nano urea, which increases surface area and improves interaction with the surrounding environment. This improved

nutrient absorption may lead to a greater number of side shoots [31]. The lower number of lateral shoots noted with urea treatments (T6 and T7) might be due to the rapid loss of urea from the soil, thereby reducing its uptake by the plants. Panda et al. [40] in tomato acquired comparable results by the application of nano urea.

3.2 Flowering parameters

Flower bud initiation time showed significant disparity among treatments, with values fluctuating between 109.17 and 153.57 days (Fig. 3A). The earliest onset occurred in T3V1 (109.17 days), followed by T2V1 (111.90 days) and T1V1 (114.23 days). In contrast, T7V2 took the longest time (153.57 days), representing a 28.91% increase over the shortest duration. The minimum number of days for flower bud initiation was obtained in nano urea treatment (T2 and T3) because the optimum dose of nitrogen, as larger amounts of nitrogen lead to the vegetative growth of the plant which is continued for longer times that delays the bud initiation of plant whereas, small amount of nitrogen also delays the bud initiation. The earliness in bud formation at lower nitrogen rates and delayed flowering with increased doses was also reported by Thaneshwari et al. [58] in hydrangea. The maximum number of days for flower bud initiation was noted under urea application (T6 and T7) might be due to the low stability of urea in the soil, which hampers its availability for plant uptake. These findings affirm the superior effectiveness of T3 fertilization in promoting early bud development

The duration required for flowering initiation varied notably across the treatments, ranging from 138.50 to 182.57 days (Fig. 3B). T3V1 reached flowering earliest (138.50 days), closely followed by T2V1 (141.00 days) and T1V1 (114.23 days). T7V2 took the longest (182.57 days), which is 24.14% greater than the shortest recorded value. The earliest onset of flowering was observed in the nano urea treatments (T2 and T3), which can be attributed to the balanced nitrogen application. Excessive nitrogen encourages extended vegetative development, delaying bud formation, while inadequate nitrogen also slows down this process. Urea treatments (T6 and T7) recorded the highest number of days to flowering, possibly because of its rapid leaching and low persistence in the soil, which restricts nutrient availability to plants. These observations underscore the positive influence of T3 fertilization in accelerating flowering. The present finding aligned with the existing finding of Grewal and Thakur [16] and Sharma et al. [54] that an appropriate nitrogen level promoted earlier flowering, whereas higher nitrogen doses resulted in delayed flowering in plants.

Distinct flower diameter was recorded across treatments and cultivars, with measurements ranging from 13.81 cm to 16.23 cm (Table 4). T3V2 exhibited the broadest flowers (16.23 cm), T3V1 (16.05 cm) and T4V2 (15.75 cm) respectively. In contrast, flowers in T7V1 were 14.91% smaller than the largest diameter observed. The distinct diameters observed in different cultivars can be attributed to their unique genetic profiles. The use of nano urea (T2 and T3) led to increased flower diameter, which can be linked that nanoparticles improved photosynthetic performance and nutrient uptake efficiency, which in turn supports robust growth and efficient partitioning of assimilates to the flowers [44]. Under urea applications (T6 and T7), the smallest flower diameter found which may be due to sub optimal nutrient

availability. The effect of nano urea on flower diameter has also been noticed by Davarpanah et al. [9] in pomegranate, Soundarya et al. [55] in sunflower and Venkatesh et al. [64] in marigold.

Table 4

Effect of split application of urea and nano-urea on flowering parameters of chrysanthemum cvs 'White Star' and 'Yellow Star'

Nutritional modules	Variety	Diameter of flower	Number of cut stem/plant	Number of cut stem/m ²	Length of cut stem	Weight of cut stem	Duration of flowering
T1	V1	14.90 ± 0.33 ^{ef}	5.63 ± 0.25 ^{bc}	84.33 ± 1.53 ^b	103.55 ± 0.75 ^{ef}	122.55 ± 1.78 ^{cde}	19.9067 ± 0.41 ^{def}
T2	V1	14.96 ± 0.12 ^{def}	6.03 ± 0.15 ^{ab}	91.00 ± 2.00 ^a	108.13 ± 0.96 ^{abcd}	131.23 ± 1.30 ^b	21.44 ± 0.07 ^{bc}
T3	V1	16.05 ± 0.08 ^{ab}	6.37 ± 0.22 ^a	95.33 ± 1.53 ^a	109.30 ± 0.64 ^{ab}	137.25 ± 1.28 ^a	21.94 ± 0.92 ^b
T4	V1	14.85 ± 0.23 ^{ef}	5.53 ± 0.15 ^c	83.67 ± 1.15 ^b	106.13 ± 1.66 ^{bcde}	123.74 ± 1.24 ^{cd}	19.55 ± 0.48 ^{defg}
T5	V1	14.56 ± 0.25 ^{fg}	5.37 ± 0.15 ^{cd}	80.33 ± 2.52 ^{bc}	103.25 ± 0.56 ^{ef}	117.50 ± 1.39 ^{efg}	19.31 ± 0.28 ^{efg}
T6	V1	14.09 ± 0.11 ^{gh}	5.03 ± 0.15 ^{de}	76.33 ± 1.53 ^c	101.32 ± 1.09 ^{fg}	112.09 ± 1.40 ^g	18.75 ± 0.24 ^{fg}
T7	V1	13.81 ± 0.26 ^h	4.67 ± 0.15 ^{ef}	70.33 ± 1.53 ^d	97.55 ± 0.81 ^h	100.36 ± 1.66 ^h	18.35 ± 0.15 ^g
T1	V2	15.53 ± 0.26 ^{bcd}	3.77 ± 0.15 ^{ghi}	56.67 ± 1.53 ^f	104.87 ± 2.77 ^{cdef}	124.20 ± 1.28 ^c	21.55 ± 0.12 ^{bc}
T2	V2	15.69 ± 0.14 ^{abc}	3.87 ± 0.25 ^{gh}	58.33 ± 2.08 ^{ef}	109.22 ± 0.37 ^{ab}	134.42 ± 3.93 ^{ab}	23.55 ± 0.19 ^a
T3	V2	16.23 ± 0.18 ^a	4.23 ± 0.06 ^{fg}	63.33 ± 1.53 ^e	110.40 ± 1.07 ^a	138.90 ± 2.11 ^a	24.23 ± 0.55 ^a
T4	V2	15.75 ± 0.22 ^{abc}	3.63 ± 0.12 ^{hi}	54.00 ± 2.0 ^{fg}	108.26 ± 1.33 ^{abc}	130.00 ± 1.47 ^b	20.57 ± 0.38 ^{cd}
*T ₁ : 25 ppm nano urea twice in a week; *T ₂ : 50 ppm nano urea once in a week; *T ₃ : 100 ppm nano urea once in fortnight; *T ₄ : 2500 ppm urea twice in a week; *T ₅ : 5000 ppm urea once in a week; *T ₆ : 10000 ppm urea once in fortnight; *T ₇ : Basal dose 30 g each of NPK.							
V1= 'White Star', V2= 'Yellow Star'							
Mean values with same superscripted letters in each column are not significantly different according to Tukey's HSD test at P < 0.05.							

Nutritional modules	Variety	Diameter of flower	Number of cut stem/plant	Number of cut stem/m ²	Length of cut stem	Weight of cut stem	Duration of flowering
T5	V2	15.60 ± 0.06 ^{bc}	3.40 ± 0.10 ^{hij}	51.00 ± 1.0 ^{gh}	104.54 ± 0.99 ^{def}	118.20 ± 2.32 ^{def}	20.45 ± 0.43 ^{cde}
T6	V2	15.31 ± 0.24 ^{cde}	3.33 ± 0.15 ^{ij}	50.33 ± 1.53 ^{gh}	102.29 ± 0.95 ^{fg}	116.11 ± 2.0 ^{fg}	19.47 ± 0.45 ^{defg}
T7	V2	13.95 ± 0.17 ^{gh}	3.13 ± 0.12 ^j	47.33 ± 1.53 ^h	99.06 ± 1.06 ^{gh}	101.43 ± 1.56 ^h	19.47 ± 0.45 ^{defg}
*T ₁ : 25 ppm nano urea twice in a week; *T ₂ : 50 ppm nano urea once in a week; *T ₃ : 100 ppm nano urea once in fortnight; *T ₄ : 2500 ppm urea twice in a week; *T ₅ : 5000 ppm urea once in a week; *T ₆ : 10000 ppm urea once in fortnight; *T ₇ : Basal dose 30 g each of NPK.							
V1= 'White Star', V2= 'Yellow Star'							
Mean values with same superscripted letters in each column are not significantly different according to Tukey's HSD test at P < 0.05.							

The production of marketable cut stems per plant varies from 3.13 to 6.37, showed significant fluctuations among the treatments and cultivars (Table 4). The greatest output was noted in T3V1 (6.37), with T2V1 (6.03) and T1V1 (5.70) trailing. The minimum stem count was recorded in T7V2 (3.13), reflecting a 50.86% decline from the highest value. The higher number marketable cut stems per plant observed under nano urea treatments (T2 and T3) may be attributed to its fine particle size and greater density, which enhance surface area for nutrient exchange and facilitate improved absorption, stimulating marketable cut stems proliferation (25). The lower number of marketable cut stems per plant noted with urea treatments (T6 and T7) might be due to that the availability to the plants was 3–4 days only [22]. Increase in the number of stems per plant have also been noticed by, 35 and Velmurugan et al. [63] in rice.

The number of harvestable stems per square meter varied significantly, falling between 47.33 and 95.33 (Table 4). The greatest stem density was observed in T3V1 (95.33), followed by T2V1 (91.00) and T1V1 (84.33). The lowest density was recorded in T7V2 (47.33), amounting to a 50.35% decrease from the maximum. The superior efficacy of nano urea treatments (T2 and T3) is likely due to their nanoscale particle size and elevated formulation density, which significantly increase the reactive surface area, thereby enhancing nutrient uptake efficiency. This improved absorption contributes to a greater yield of marketable cut stems per square meter. In contrast, conventional urea treatments (T6 and T7) resulted in fewer marketable stems, possibly owing to restricted nutrient availability, as plant uptake is largely limited to a brief period of 3–4 days post-application [22]. Similar findings regarding increased stem production per square meter have been documented by Panda et al. [40] in tomato and Gayathri et al. [12] in safflower.

Stem elongation varied across the treatments, with values extending from 97.55 cm to 110.40 cm (Table 4). T3V2 recorded the greatest length (110.40 cm), followed closely by T3V1 (109.30 cm) and T2V1 (109.22 cm). Meanwhile, T7V1 produced the shortest stems, which were 11.64% shorter than the maximum. The longest plant was found with the application of nano urea treatment (T2 and T3) due to that nano urea promotes optimal nitrogen availability, which enhances meristematic functions and leads to extended internode growth, ultimately increasing cut stem length [6]. In contrast, under conventional urea treatments, nitrogen loss through leaching limits its availability to the plant, which likely accounts for the shorter stem lengths observed in treatments T6 and T7. The findings of the present study are in line with earlier reports on nano urea efficacy in other crops, Al-Juthery et al. [2] in wheat, Rathore et al. [48] and Samui et al. [51] in maize.

Appreciable differences in stem weight were recorded among the treatments, with measurements ranging from 100.36 g to 138.90 g (Table 4). The heaviest stems were produced under T3V2 (138.90 g), followed by T3V1 (137.25 g) and T2V2 (134.42 g). The lightest stems were observed in T7V2, which showed a 27.75% reduction from the maximum recorded value. The increased stem weight of cut flowers using nano urea application (T2 and T3) is likely due to their efficient and balanced nutrient delivery, which stimulates leaf development and promotes the biosynthesis of carbohydrates and proteins, ultimately enhancing stem mass [30]. On the other hand, with conventional urea treatments, the effective period during which nitrogen was available for plant uptake was confined to 3–4 days resulted in less stem mass. Similar outcomes have been reported by Benzon et al. [5], Sharifi and Namvar [53] and Rani et al. [46].

Vase life varied from 20.93 to 27.60 days across different treatments and cultivars (Fig. 3C). T3V2 had the longest postharvest life (27.60 days), with T2V2 (26.93 days) and T4V2 (26.83 days) close behind. The shortest vase life was noted in T7V1 (20.93 days), reflecting a 24.17% reduction. This demonstrates the effectiveness of T3 nutrient management in prolonging floral shelf life. The improved vase life of chrysanthemums under nano urea treatments (T2 and T3) due to optimal nitrogen levels can be attributed to enhanced carbohydrate accumulation, which delays senescence and supports flower longevity. Optimal nitrogen also maintains stem rigidity by reducing succulence, enabling better support for floral structures. However, with urea treatments (T6 and T7) low and high nitrogen may deplete sugar reserves and promote protein breakdown, negatively affecting post-harvest life. Similar observations were reported by Thaneshwari et al. [58] and Sharma et al. [54].

Flowering span across treatments showed clear differences, with values ranging from 18.35 to 24.23 days (Table 4). The extended blooming period was observed in T3V2 (24.23 days), followed by T2V2 (23.55 days) and T3V1 (21.94 days). The shortest flowering period was recorded in T7V1 (18.35 days), indicating a 24.27% decline compared to the maximum. The disparity in flowering among cultivars may be their distinct genetic characteristics. The longest flowering duration with the application of nano urea treatments (T2 and T3) was due to sustained nitrogen availability. Nano urea facilitated a balanced vegetative-to-reproductive transition, contributing to timely flowering and extended floral duration due to continuous carbohydrate and protein availability [44]. On the other hand, with urea treatments (T6 and

T7) effect the flowering span due to low availability of nitrogen. These findings are consistent with previous research highlighting nitrogen's regulatory role in flowering dynamics by Thaneshwari et al. [58].

3.3 Soil parameters

Appreciable divergence in soil pH before and after crop growth was found across treatments and cultivars, with a recorded span between 6.31 and 6.58 was found after crop growth (Table 5). The highest pH was obtained in T3V2 (6.58), with T2V2 (6.57) and T4V2 (6.54) in close range. Conversely, T7V1 obtained the lowest value (6.31), which was 4.10% lower than the peak reading. Nitrogen application influenced soil pH across treatments, with a temporary decline observed due to urea hydrolysis. In conventional urea treatments (particularly T6 and T7), more pronounced acidification was recorded, likely due to the rapid conversion of urea into ammonium and bicarbonate, which interacts with soil hydrogen ions, lowering the pH [67]. This acidification was amplified under excessive nitrogen levels, consistent with earlier findings by Wells et al. [68]. In contrast, nano urea treatments resulted in less drastic changes in pH, likely due to its controlled nitrogen release and improved uptake, which minimized excessive accumulation and hydrolysis in the soil. Our findings were in accordance with the studies of Hati et al. [20], Theresa et al. [59] and Rathore et al. [48].

Table 5
Effect of split application of urea and nano-urea on soil status of chrysanthemum cvs 'White Star' and 'Yellow Star'

Nutritional modules	Variety	Soil pH	Soil EC	Soil Nitrogen	Soil Phosphorus	Soil Potassium	Organic Carbon
T1	V1	6.41 ± 0.01 ^{defg}	0.77 ± 0.01 ^{ab}	326.77 ± 0.18 ^d	19.49 ± 0.25 ^C	213.80 ± 0.23 ^{fg}	1.04 ± 0.01 ^{ab}
T2	V1	6.44 ± 0.02 ^{bcdef}	0.69 ± 0.03 ^c	304.51 ± 0.17 ^h	18.64 ± 0.12 ^{de}	211.54 ± 0.08 ^h	1.03 ± 0.01 ^{bcd}
T3	V1	6.47 ± 0.07 ^{abcde}	0.67 ± 0.01 ^c	292.70 ± 0.92 ^j	18.31 ± 0.22 ^e	209.61 ± 0.38 ⁱ	1.02 ± 0.01 ^d
T4	V1	6.42 ± 0.02 ^{cdefg}	0.70 ± 0.05 ^{bc}	315.80 ± 0.17 ^f	18.72 ± 0.15 ^{de}	212.58 ± 0.51 ^{gh}	1.03 ± 0.01 ^{bcd}
T5	V1	6.37 ± 0.02 ^{efg}	0.77 ± 0.03 ^{ab}	361.77 ± 0.22 ^c	19.56 ± 0.48 ^c	215.92 ± 0.11 ^{de}	1.04 ± 0.01 ^{abc}
T6	V1	6.34 ± 0.05 ^{fg}	0.79 ± 0.04 ^a	379.18 ± 0.89 ^a	19.79 ± 0.06 ^{bc}	217.20 ± 0.50 ^{bcd}	1.04 ± 0.01 ^{ab}
T7	V1	6.31 ± 0.02 ^g	0.79 ± 0.01 ^a	304.77 ± 1.56 ^h	20.66 ± 0.21 ^a	218.49 ± 0.43 ^{ab}	1.03 ± 0.01 ^{bcd}
T1	V2	6.51 ± 0.01 ^{abcd}	0.78 ± 0.02 ^a	327.64 ± 0.36 ^d	19.51 ± 0.06 ^C	214.88 ± 0.16 ^{ef}	1.033 ± 0.01 ^{abcd}
T2	V2	6.57 ± 0.04 ^{ab}	0.69 ± 0.02 ^{bc}	306.15 ± 0.44 ^h	18.68 ± 0.32 ^{de}	212.52 ± 0.30 ^{gh}	1.03 ± 0.01 ^{abcd}
T3	V2	6.58 ± 0.07 ^a	0.67 ± 0.02 ^c	297.18 ± 0.56 ⁱ	18.62 ± 0.11 ^e	210.05 ± 0.95 ⁱ	1.02 ± 0.01 ^{cd}
T4	V2	6.54 ± 0.01 ^{abc}	0.73 ± 0.02 ^{abc}	317.80 ± 0.06 ^e	19.28 ± 0.06 ^{cd}	213.50 ± 0.45 ^g	1.03 ± 0.01 ^{abcd}
T5	V2	6.49 ± 0.08 ^{abcde}	0.783 ± 0.01 ^a	364.17 ± 0.42 ^b	19.73 ± 0.18 ^c	216.60 ± 0.46 ^{cd}	1.04 ± 0.01 ^{abc}
T6	V2	6.40 ±	0.80 ±	380.91 ±	20.38 ±	217.88 ±	1.04 ±
*T ₁ : 25 ppm nano urea twice in a week; *T ₂ : 50 ppm nano urea once in a week; *T ₃ : 100 ppm nano urea once in fortnight; *T ₄ : 2500 ppm urea twice in a week; *T ₅ : 5000 ppm urea once in a week; *T ₆ : 10000 ppm urea once in fortnight; *T ₇ : Basal dose 30 g each of NPK.							
V1= 'White Star', V2= 'Yellow Star'							
Mean values with same superscripted letters in each column are not significantly different according to Tukey's HSD test at P < 0.05.							

Nutritional modules	Variety	Soil pH	Soil EC	Soil Nitrogen	Soil Phosphorus	Soil Potassium	Organic Carbon
		0.05 ^{defg}	0.02 ^a	0.37 ^a	0.15 ^{ab}	0.10 ^{bc}	0.01 ^{ab}
T7	V2	6.38 ± 0.04 ^{efg}	0.81 ± 0.02 ^a	308.59 ± 0.53 ^g	20.71 ± 0.22 ^a	219.46 ± 0.49 ^a	1.047 ± 0.01 ^a
*T ₁ : 25 ppm nano urea twice in a week; *T ₂ : 50 ppm nano urea once in a week; *T ₃ : 100 ppm nano urea once in fortnight; *T ₄ : 2500 ppm urea twice in a week; *T ₅ : 5000 ppm urea once in a week; *T ₆ : 10000 ppm urea once in fortnight; *T ₇ : Basal dose 30 g each of NPK.							
V1= 'White Star', V2= 'Yellow Star'							
Mean values with same superscripted letters in each column are not significantly different according to Tukey's HSD test at P < 0.05.							

Discernible differences in EC before and after crop growth were identified under various nutritional treatments and cultivars, with readings varying from 0.67 to 0.81 was found after crop growth (Table 5). The lowest EC was noted in T3V1 and T3V2 (0.67), while T2V1 followed with 0.69. The highest EC value was observed in T7V2 (0.81), constituting a 17.28% increase above the lowest. EC values were elevated under conventional urea application (T6 and T7), which can be attributed to the accumulation of residual salts such as phosphorus and potassium not efficiently taken up by the plants. This is linked to low nitrogen use efficiency and nutrient leaching associated with urea. In nano urea modules (T1, T2 and T3), the EC remained comparatively stable, indicating balanced nutrient uptake and reduced salt accumulation in the soil. Our results aligned with the finding of Rathore et al. [48] in maize.

Soil nitrogen content before and after crop growth exhibited significant fluctuation, ranging from 292.70 to 380.91 was found after crop growth between cultivars and treatments (Table 5). The most elevated levels were detected in T6V2 (380.91), followed by T6V1 (379.18) and T5V2 (364.17). The lowest nitrogen level was seen in T3V1 (292.70), indicating a 23.24% reduction from the highest. The data affirms that nitrogen uptake was maximized under T3 fertilization, with V1 responding more favourably. Residual soil nitrogen levels were significantly higher in conventional urea plots (T6 and T7), reflecting poor nitrogen uptake efficiency due to leaching and volatilization losses common issues with urea, which provides only 30–40% use efficiency. Conversely, nano urea-treated plots, particularly T3, exhibited lower residual nitrogen post-harvest. This indicates effective nitrogen assimilation and internal nitrogen regulation within the plant, where surplus nitrogen is sequestered in vacuoles and released based on demand [63], minimizing environmental losses. Our findings were consistent with the results reported by Lahari et al. [30], Gayathri et al. [12] in safflower and Sahu et al. [50] in rice.

Phosphorus levels in soil before and after crop growth fluctuated among treatments and cultivars with value ranging from 18.31 to 20.71 after crop growth (Table 5). T7V2 showed the highest content (20.71), with T7V1 (20.66) and T6V2 (20.38) close behind. T3V1 recorded the lowest phosphorus (18.31), 11.59% less than the peak. These results underline the efficient phosphorus utilization under T3 fertilization,

especially by cultivar V1. Conventional urea modules showed higher residual phosphorus levels, likely resulting from insufficient nitrogen uptake disrupting the N:P balance, thus limiting phosphorus absorption by the crop. In contrast, nano urea treatments resulted in lower post-harvest phosphorus content, suggesting improved nutrient synchronization and root uptake. Efficient utilization under nano urea is also supported by earlier studies by Algym et al. [3] and Pandav et al. [41].

Substantial variation in potassium content before and after crop growth was observed across treatments, extending from 209.61 to 219.46 after crop growth (Table 5). T7V2 recorded the maximum value (219.46), while T7V1 (218.49) and T6V2 (217.88) followed. T3V1 recorded the minimum (209.61), indicating a 4.49% drop from the top value. This demonstrates efficient potassium absorption under T3 treatment, particularly in cultivar V1. Residual potassium followed a similar trend, with higher levels recorded in conventional urea plots. The inefficient nitrogen absorption in these treatments may have led to reduced overall plant nutrient demand, limiting potassium uptake. Nano urea-treated plants demonstrated better potassium utilization, reflected by reduced post-harvest soil K, suggesting effective translocation and involvement in physiological activities supporting growth and flowering. The present findings corroborate the results obtained by Lahari et al. [30] and Velmurugan et al. [63] in field crops.

The concentration of organic carbon in soil before and after crop growth varied significantly between treatments, with a range from 1.02 to 1.05 after crop growth (Table 5). The peak value was identified in T7V2 (1.05), with T6V1 and T5V1 each following at 1.04. The lowest was recorded in T3V1 (1.02), a 2.86% decrease from the highest. T3 fertilization proved most effective for organic carbon assimilation, with cultivar V1 performing notably well. Higher organic carbon content was recorded in urea-treated plots (T6 and T7), which may be due to reduced microbial activity and slower organic matter decomposition stemming from suboptimal nutrient uptake. In nano urea modules, particularly T3, a decline in organic carbon was observed, likely due to enhanced root activity, greater microbial biomass turnover, and accelerated nutrient cycling stimulated by efficient nano urea absorption. Similar outcomes have been reported by Lahari et al. [30] and Sahu et al. [50].

4 Conclusion and future direction

The findings of this study underscore the potential of split nitrogen application using nano urea as a sustainable and efficient strategy for enhancing growth and flowering in chrysanthemum under polyhouse conditions. Nano urea, due to its higher nitrogen use efficiency, controlled release and superior foliar uptake, outperformed conventional urea in promoting key vegetative and reproductive traits. Nutritional module T3, with an optimal nano urea concentration, led to better plant health, flower yield and quality. Furthermore, the reduced nutrient residues in the soil and minimal leaching losses reflect its environmentally benign nature. These results highlights the potential of nano urea as a viable alternative to conventional nitrogen fertilizers for precision nutrient management in protected floriculture systems. Future research should focus on multi-location validation of these results across diverse agro-climatic conditions, long-term assessment of soil health, microbial interactions and integration of nano

urea with other precision nutrient management approaches. Economic feasibility and scalability studies will also be essential to facilitate its large-scale adoption in commercial chrysanthemum cultivation.

Declarations

Permission statement

The plant material used in this study was obtained from the institutional research farm of Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan. No specific permission was required as the study did not involve endangered or protected plant species.

Ethics approval and consent to participate

This study did not involve human participants or animals. The plant material used in this study complied with relevant institutional, national and international guidelines. The experiment was conducted on cultivated chrysanthemum plants under controlled polyhouse conditions, and no wild or protected species were involved. No specific permissions or licences were required for the use of plant material obtained from the institutional research farm.

Consent to publication

Not applicable.

Competing interests

No potential conflict of interest was reported by the author(s).

Funding

No funding was received to support the preparation of this article.

Author Contribution

Shikha Rana conducted the experimental work, analysed the data and drafted the manuscript. S. R. Dhiman supervised the study and provided critical guidance. Puja Sharma, Upender Singh and Anju Sharma reviewed and approved the final version of manuscript

Acknowledgement

The authors acknowledge the support and assistance provided by Department of Floriculture and Landscape Architecture, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan.

Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

1. Acharya P, Solanki NS, Gehlot JK, Rajwaniya A, Jaiswani S, Champawat TS, Tyagi S, Panchal K. Effect of nano urea on growth and yield attributes of Indian mustard (*Brassica juncea* L). Int J Res Agron. 2024;7(12):236–8. <https://doi.org/10.33545/2618060X.2024.v7.i12Sd.2139>.
2. Al-Juthery HW, Habeeb KH, Altaee FJK, Al-Taey DK, Al-Tawaha ARM. Effect of foliar application of different sources of nano-fertilizers on growth and yield of wheat. Bioscience Res. 2018;15(4):3988–97.
3. Algym AJK, Alasady MHS. Effect of the method and level of adding NPK nanoparticles and mineral fertilizers on growth and yield of yellow corn and mineral nutrient content of plant parts. Plant Archives. 2020;20(1):38–43.
4. Anderson K, Bows A, Mander S. From long-term targets to cumulative emission pathways: Reframing UK climate policy. Energy Policy. 2008;36(1):3714–22. <https://doi.org/10.1016/j.enpol.2008.07.003>.
5. Benzon LHR, Rubenecia MRU, Ultra VU, Lee. Nano fertilizer affects the growth, development and chemical properties of rice. Int J Agron Agricultural Res. 2015;7(1):105–17.
6. Bhargavi G, Sundari A. Effect of nano urea on the growth and yield of rice (*Oryza sativa* L.) under SRI in the Cauvery delta zone of Tamil Nadu. Crop Res. 2023;58(1–2):12–7. <https://doi.org/10.31830/2454-1761.2023.cr-885>.
7. Chaudhary S, Shah HP, Singh A, Tandel BM, Ninama V. Effect of pinching and growth retardants on growth and flowering of pot chrysanthemum. J Pharm Innov. 2023;12(12):1604–8.
8. Congreves KA, Otchere O, Ferland D, Farzadfar S, Williams S, Arcand MM. Nitrogen use efficiency definitions of today and tomorrow. Front Plant Sci. 2021;12(1):637108. <https://doi.org/10.3389/fpls.2021.637108>.
9. Davarpanah S, Tehranifar A, Davarynejad G. Effects of foliar nano nitrogen and urea fertilizers on physical and chemical properties of pomegranate fruits. HortScience. 2017;52(2):288–94. <https://doi.org/10.21273/HORTSCI11248-16>.
10. Dhamankar C, Mankar D, Pusdekar V, Mane S, Nakat S, Dodewar P. Effect of nano urea on growth of drilled paddy. J Pharm Innov. 2023;12(8):441–3.
11. Faust JE, Dole JM. The Global Cut Flower and Foliage Industry. Wallingford, UK: CABI Publishing; 2021. <https://doi.org/10.1079/9781789247602.0001>.
12. Gayathri PA, Ghuge SB, Shinde SA, Mahesh S, Pawar AV. Nitrogen rates and nano urea effects on physiological parameters and yield of safflower (*Carthamus tinctorius* L). Int J Environ Clim Change.

- 2023;13(10):3974–81. <https://doi.org/10.9734/ijecc/2023/v13i103071>.
13. Ghule AL, Rawat VV, Johar V, Raut RN, Jadhav AA. Nano urea: Predictive insights and real-world implications for sustainable agriculture. *J Adv Biology Biotechnol*. 2025;28(4):546–58. <https://doi.org/10.9734/jabb/2025/v28i42213>.
 14. Gomez KA, Gomez AA. *Statistical Procedures for Agricultural Research*. 2nd ed. New York, USA: Wiley; 1984.
 15. Goud GMK, Sudhakar KS, Pasha L, Madhavi A. Evaluation of the foliar application of nano urea on the performance of rabi sunflower (*Helianthus annuus* L). *Int J Environ Clim Change*. 2022;12(11):2700–6. <https://doi.org/10.9734/ijecc/2022/v12i1131258>.
 16. Grewal HS, Thakur T. Effect of nitrogen application on growth and flowering in chrysanthemum. *Agricultural Res J*. 2016;53(4):505–8. <https://doi.org/10.5958/2395-146X.2016.00100.9>.
 17. Grzyb A, Wolna-Maruwka A, Niewiadomska A. The significance of microbial transformation of nitrogen compounds in the light of integrated crop management. *Agronomy*. 2021;11(1):1415. <https://doi.org/10.3390/agronomy11071415>.
 18. Gupta R, Gupta A, Jain S, Singh D, Verma N. Chrysanthemum production, viral diseases and their management. In: Raj SK, Gaur RK, Yin Z, editors. *Virus Diseases of Ornamental Plants*. Singapore: Springer; 2021. pp. 317–39. https://doi.org/10.1007/978-981-16-3919-7_14.
 19. Hasaneen MNAG, Abdel-Aziz HMM, Omer AM. Effect of foliar application of engineered nanomaterials on growth of French bean plant. *Biochem Biotechnol Res*. 2016;4(4):68–76.
 20. Hati KM, Swarup A, Mishra B, Manna MC, Wanjari RH, Mandal KG, Misra AK. Impact of long-term application of fertilizer, manure and lime under intensive cropping on physical properties and organic carbon content of an Alfisol. *Geoderma*. 2008;148(2):173–9. <https://doi.org/10.1016/j.geoderma.2008.09.015>.
 21. Jackson ML. *Soil Chemical Analysis*. New Delhi, India: Prentice Hall of India Pvt. Ltd.; 1973.
 22. Jangir N, Suman, Saxena S, Yadav S, and Nishikan. Nano urea: Environment-friendly and better substitute for urea. *Just Agric*. 2021;2(1):34–7.
 23. Jiang K, Peng S, Yin Z, Li X, Xie L, Shen M, Li D, Gao J. Effects of N, P and K nutrition levels on growth, flowering attributes and functional components in *Chrysanthemum morifolium*. *Horticulturae*. 2024;10(1):226. <https://doi.org/10.3390/horticulturae10030226>.
 24. Kamal S, Rana A, Devi R, Kumar R, Yadav N, Chaudhari AA, Yadav S, Singh S, Bhargava B, Singh S, Chauhan R. Stability assessment of chrysanthemum hybrids through AMMI and GGE biplot analysis. *Sci Rep*. 2024;14(1):14170. <https://doi.org/10.1038/s41598-024-61994-4>.
 25. Kantwa S, Yadav LR. Nano urea: Application and significance. *Just Agric*. 2022;2(7):1–6.
 26. Karthika KS, Rashmi I, Parvathi MS. Biological functions, uptake and transport of essential nutrients in relation to plant growth. *Plant nutrients and abiotic stress tolerance*. Springer Singapore; 2018. pp. 1–49.

27. Kumar YO, Tiwari KN, Singh T, Raliya R. Nano fertilizers and their role in sustainable agriculture. *Annals Plant Soil Res.* 2021;23(3):238–55. <https://doi.org/10.47815/aprsr.2021.10067>.
28. Kumar Y, Tiwari KN, Nayak RK, Rai A, Singh SP, Singh AN, Tomar H, Singh T, Raliya R. Nanofertilizers for enhancing nutrient use efficiency and crop productivity. *Indian J Fertilisers.* 2020;16(8):772–86.
29. Kumari G, Dwivedi A, Shukla A, Yadav A. Impact of sowing techniques and nano urea application on wheat growth and yield. *Int J Plant Soil Sci.* 2025;37(3):185–94. <https://doi.org/10.9734/ijpss/2025/v37i35358>.
30. Lahari S, Hussain SA, Parameswari YS, Sharma SHK. Grain yield and nutrient uptake of rice as influenced by nano forms of nitrogen and zinc. *Int J Environ Clim Change.* 2021;11(7):1–6. <https://doi.org/10.9734/ijecc/2021/v11i730434>.
31. Lin D, Xing B. Phytotoxicity of nanoparticles: Inhibition of seed germination and root growth. *Environ Pollut.* 2007;150(2):243–50. <https://doi.org/10.1016/j.envpol.2007.01.016>.
32. Masjedi SK, Kazemi A, Moeinnadini M, Khaki E, Olsen SI. Urea production: An absolute environmental sustainability assessment. *Sci Total Environ.* 2024;908(1):168225. <https://doi.org/10.1016/j.scitotenv.2023.168225>.
33. Mekapogu M, Kwon OK, Song HY, Jung JA. Towards the improvement of ornamental attributes in chrysanthemum: Recent progress in biotechnological advances. *Int J Mol Sci.* 2022;23(20):12284. <https://doi.org/10.3390/ijms232012284>.
34. Menegat S, Ledo A, Tirado R. Greenhouse gas emissions from global production and use of nitrogen synthetic fertilisers in agriculture. *Sci Rep.* 2022;12(1):18773. <https://doi.org/10.1038/s41598-022-18773-w>.
35. Merwin HD, Peech M. Exchangeability of soil potassium in sand, silt and clay fractions as influenced by complementary exchangeable cations. *Soil Sci Soc Am J.* 1951;15(1):125–8. <https://doi.org/10.2136/SSSAJ1951.036159950015000C0026X>.
36. Midde SK, Perumal MS, Murugan G, Sudhagar R, Mattepally VS, Bada MR. Evaluation of nano urea on growth and yield attributes of rice (*Oryza sativa* L). *Chem Sci Rev Lett.* 2022;11(42):211–4.
37. Muniz MA, Barbosa JG, Grossi JAS, Orbes MY, Sá PG. Production and quality of pot chrysanthemum fertirrigated with different nitrate/ammonium relations. *Bioscience J.* 2009;25(1):75–82.
38. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate. Washington, DC, USA: United States Department of Agriculture Circular No. 939; 1954.
39. Pan B, Du Y, Chen Q, Wang Y, Chen L, Li H, Huang C, Gao K. China's chrysanthemum in the global market: Evaluating international competitiveness and influencing factors. *Front Sustainable Food Syst.* 2025;9(1):1521709. <https://doi.org/10.3389/fsufs.2025.1521709>.
40. Panda J, Nandi A, Mishra SP, Pal AK, Pattnaik AK, Jena NK. Effects of nano fertilizer on yield, yield attributes and economics of tomato (*Solanum lycopersicum* L). *Int J Curr Microbiol Appl Sci.* 2020;9(5):2583–91. <https://doi.org/10.20546/ijcmas.2020.905.295>.

41. Pandav DM, Talathi MS, Bodake PS, Chavan VG, More SS, Pethe UB, Rajemahadik VA, Ghodake SS, Mote GK. Response of nitrogen level and nano urea on mustard (*Brassica juncea* L.) under Konkan conditions. *Pharm Innov J.* 2022;11(12):2055–61.
42. Panwar S, Panigrahi S, Mehraj U, Kumari P. 2024. *Chrysanthemum morifolium*. In: *Edible Flowers*. Academic Press, pp. 65–85. <https://doi.org/10.1016/B978-0-443-13769-3.00005-4>
43. Pathania S, Dhiman SR, Kashyap B, Kumar A, Kaushal R, Gupta RK, Alkahtani J, AlMunqedhi BM. Assessing the influence of planting time and fertilization on growth, flowering, yield and soil properties of chrysanthemum. *J King Saud Univ - Sci.* 2024;36(9):103418. <https://doi.org/10.1016/j.jksus.2024.103418>.
44. Pooja LR, Kumar S, Singh R, Prasad S. Nanostructured urea fertilizer (nano urea): A promising approach to sustainable agriculture. *Food Sci Rep.* 2023;4(5):84–91.
45. Raliya R, Saharan V, Dimkpa C, Biswas P. Nanofertilizer for precision and sustainable agriculture: Current state and future perspectives. *J Agric Food Chem.* 2017;66(26):6487–503. <https://doi.org/10.1021/acs.jafc.7b02178>.
46. Rani B, Nirali B, Zalawadia NM, Rushang K. Effect of different levels of chemical and nano nitrogenous fertilizers on yield and yield attributes of sorghum (*Sorghum bicolor* L). *Int J Curr Microbiol Appl Sci.* 2019;8(8):2878–84. <https://doi.org/10.20546/ijcmas.2019.808.332>.
47. Rathnayaka RMNN, Mahendran S, Iqbal YB, Rifnas LM. Influence of urea and nano nitrogen fertilizers on growth and yield of rice (*Oryza sativa* L). *Int J Res Publications.* 2018;5(2):7–8.
48. Rathore R, Hasan A, David AA, Thomas T, Reddy IS. Effect of different levels of nano urea and conventional fertilizer on soil health of maize (*Zea mays* L.) in an Inceptisol. *Pharm Innov J.* 2022;11(8):560–3.
49. Rawate D, Patel JR, Agrawal AP, Agrawal HP, Pandey D, Patel CR, Verma P, Chandravanshi M. Effect of nano urea on productivity of wheat (*Triticum aestivum* L.) under irrigated conditions. *Pharm Innov J.* 2022;11(9):1279–82.
50. Sahu TK, Kumar M, Kumar N, Chandrakar T, Singh DP. Effect of nano urea application on growth and productivity of rice (*Oryza sativa* L.) under midland conditions. *Pharm Innov J.* 2022;11(6):185–7.
51. Samui S, Sagar L, Sankar T, Manohar A, Adhikary R, Maitra S, Praharaj S. Growth and productivity of rabi maize as influenced by foliar application of urea and nano-urea. *Crop Res.* 2022;57(3):136–40. <https://doi.org/10.31830/2454-1761.2022.019>.
52. Saud M, Joseph M, Hemalatha M, Rajakumar D, Jothimani S, Srinivasan S. Effect of bio-organic fertilizers with nano urea spray on nitrogen economy of rice. *Pharm Innov J.* 2022;11(7):4475–80.
53. Sharifi RS, Namvar A. Effects of time and rate of nitrogen application on phenology and some agronomical traits of maize (*Zea mays* L). *J Biol Sci.* 2016;62(1):35–45.
54. Sharma N, Bala M, Singh P. Effect of different nitrogen levels on growth and flowering of chrysanthemum (*Chrysanthemum morifolium* Ramat.) cv. 'White Star'. *Agricultural Res J.* 2023;60(5). <https://doi.org/10.5958/2395-146X.2023.00101.1>.

55. Singh JP, Kumar R, Deepak D, Nag A, Kumar V, Singh BK. Nano-urea effect on India's sustainable agriculture. *Innovative Res Agricultural Sci.* 2025;1(1):146–51.
56. Soundarya K, Kumar GA, Veeresh H, Ravi S, Srinivasa DK, Kumar AMY. Effect of nano urea on growth, yield and nutrient uptake of finger millet (*Eleusine coracana* L). *Int J Plant Soil Sci.* 2024;36(9):660–7. <https://doi.org/10.9734/ijpss/2024/v36i95014>.
57. Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soils. *Curr Sci.* 1956;25(1):251–4.
58. Thaneshwari S, Dilta BS, Gupta YC. Effect of different doses of nitrogen and potassium on growth and flowering of hydrangea (*Hydrangea macrophylla*). *Ecol Environ Conserv.* 2017;23(2):127–30.
59. Theresa K, Shanmugasundaram R, Kennedy JS. Dynamic changes in soil physico-chemical properties with the application of inorganic fertilizers. *Int J Curr Microbiol Appl Sci.* 2019;8(8):2111–22. <https://doi.org/10.20546/ijcmas.2019.808.247>.
60. Tiwari S. Nano urea: A small solution with a big impact on sustainable agriculture. *Int J Res Rev.* 2023;10(1):272–8. <https://doi.org/10.52403/ijrr.20230330>.
61. Tomar M, Choudhary R, Patidar R. Nano urea - a bliss for agriculture or not. *Recent Trends Agric.* 2023;1:1–12.
62. Upadhyay PK, Dey A, Singh VK, Dwivedi BS, Singh T, Babu GAR, Rathor S, Singh SS, Shekhawat RK, K., and, Rangot M. Conjoint application of nano-urea with conventional fertilizers: An energy-efficient and environmentally robust approach for sustainable crop production. *PLoS ONE.* 2023;18(7):e0284009. <https://doi.org/10.1371/journal.pone.0284009>.
63. Velmurugan A, Subramani T, Bommayasamy N, Ramakrishna, Kumar M, Swarnam TP. Effect of foliar application of nano urea (liquid) on rice (*Oryza sativa* L). *J Andaman Sci Association.* 2021;26(2):76–81.
64. Venkatesh M, Babu KK, Prasanth P, Lakshminarayana D, Kumar SP. Effect of different nitrogen levels in combination with nano urea on growth and yield of marigold (*Tagetes erecta* L.) cv. 'Pusa Narangi Gainda'. *Pharm Innov J.* 2022;11(11):1313–7.
65. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 1934;37(1):29–38. <https://doi.org/10.1097/00010694-193401000-00003>.
66. Wamiq M, Alam K, Ahmad M, Kumar A. 2022. Nutrient management in protected cultivation. In: *Recent Advances in Protected Cultivation*. Chapter 10, pp. 185–202.
67. Wardle DA. A comparative assessment of factors which influence microbial biomass carbon and nitrogen levels in soil. *Biol Rev.* 1992;67(3):321–58. <https://doi.org/10.1111/j.1469-185X.1992.tb00728.x>.
68. Wells NS, Clough TJ, Johnson-Beebout SE, Buresh RJ. Land management between crops affects soil inorganic nitrogen balance in a tropical rice system. *Nutr Cycl Agrosyst.* 2014;100(3):315–32. <https://doi.org/10.1007/s10705-014-9644-7>.

69. Wu W, Ma BL. Understanding the trade-off between lodging resistance and seed yield and developing non-destructive methods for predicting crop lodging risk in canola production. *Field Crops Res.* 2022;288:108691. <https://doi.org/10.1016/j.fcr.2022.108691>.

70. Xing Y, Xie Y, Wang X. Enhancing soil health through balanced fertilization: A pathway to sustainable agriculture and food security. *Front Microbiol.* 2025;16:1536524. <https://doi.org/10.3389/fmicb.2025.1536524>.

71. Zhang X, Wu JZ, Lin ZX, Yuan QJ, Li YC, Liang JL, Xie Y, Su Z, Liu Y. Ameliorative effect of supercritical fluid extract of *Chrysanthemum indicum* Linn. against D-galactose-induced brain and liver injury via suppression of oxidative stress, inflammation and apoptosis. *J Ethnopharmacol.* 2019;234:44–56.

Figures

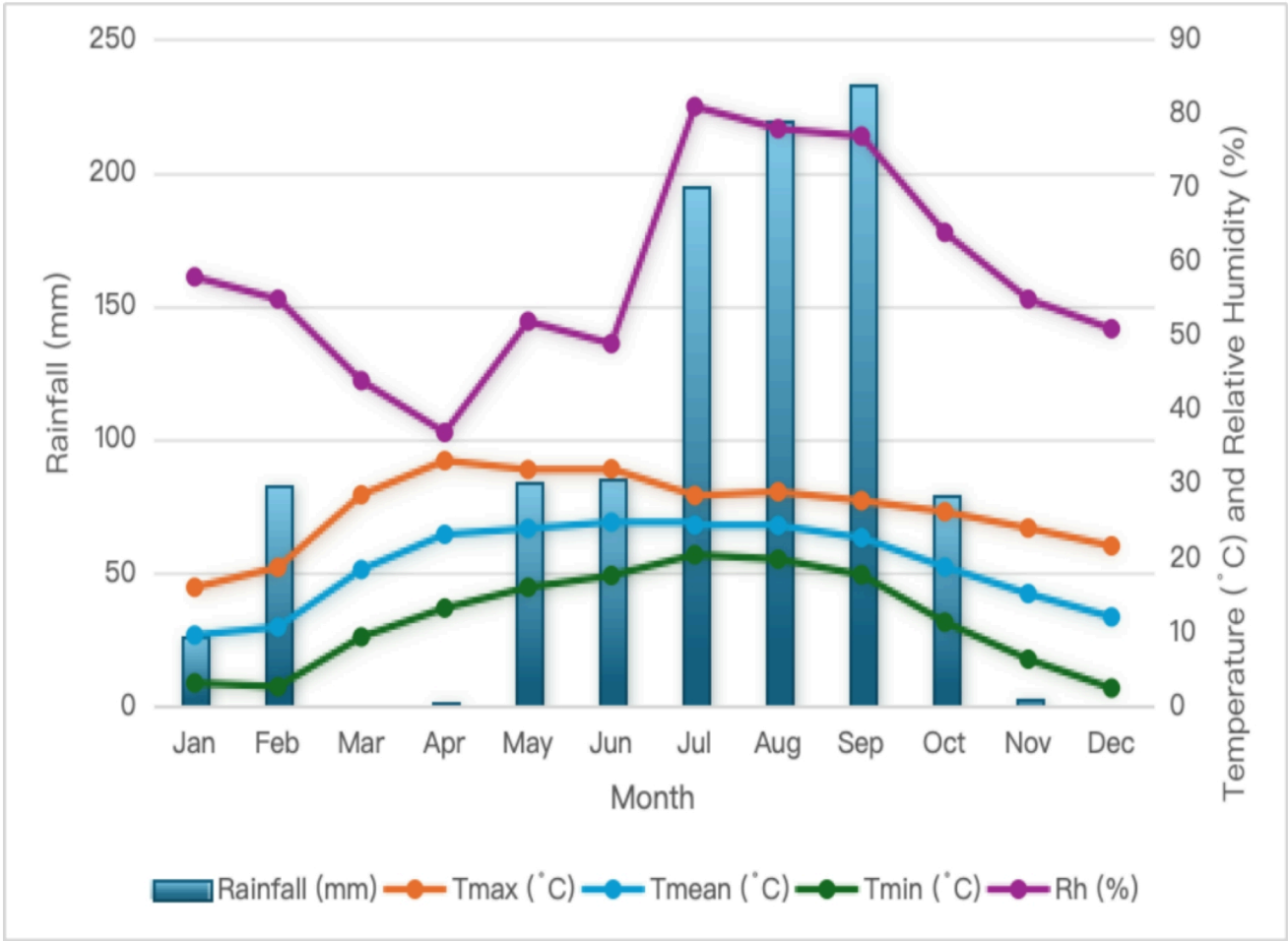


Figure 1



Figure 2

Morphological characteristics of chrysanthemum cultivars ‘White Star’ (A) and Chrysanthemum cv. ‘Yellow Star’ (B)

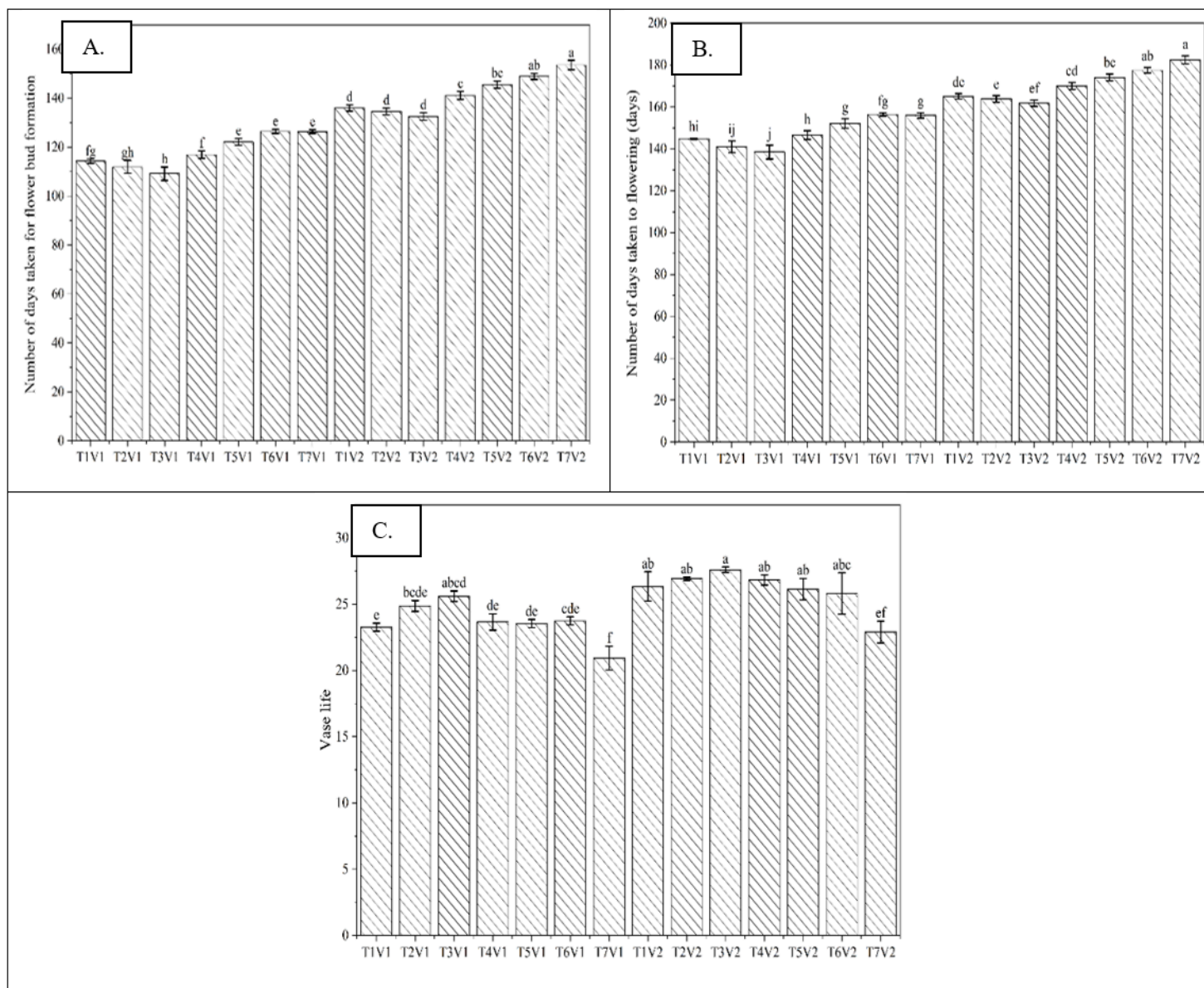


Figure 3

Effect of split application of urea and nano-urea on number of days taken for flower bud formation(A), number of days taken for flowering (B) and vase life (C).

T1: 25 ppm nano urea twice in a week; *T2: 50 ppm nano urea once in a week; *T3: 100 ppm nano urea once in fortnight; *T4: 2500 ppm urea twice in a week; *T5: 5000 ppm urea once in a week; *T6: 10000 ppm urea once in fortnight; *T7: Basal dose 30 g each of NPK.

V1= 'White Star', V2= 'Yellow Star'

Mean values with same superscripted letters in each column are not significantly different according to Tukey's HSD test at $P < 0.05$.