



Effect of Different Level of Nano Urea on Growth of Strawberry (*Fragaria X ananassa*) cv. Winter Dawn, under Prayagraj Agro Climatic Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A research study was carried out at the Horticulture Research Farm, Department of Horticulture, NAI, SHUATS, located in Prayagraj, Uttar Pradesh, during the academic years 2022-23 and 2023-2024. The experiment comprised 11 treatments involving various combinations of conventional urea and nano urea, applied at different levels and concentrations, with each treatment replicated three times in a Randomised Block Design. The main objective of the experiment was to assess

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the impact of varying concentrations of nano urea on the growth characteristics of Strawberry (*Fragaria X ananassa*) cv. Winter Dawn. Treatment T₇ [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] was found best with [9.78 (2022-23), 10.05 (2023-24) and 9.91 (Pooled)] days to new growth, [31.11 (2022-23), 32.32 (2023-24) and 31.71 (Pooled)] days to runner formation after planting, [17.11 (2022-23), 17.79 (2023-24) and 17.45 (Pooled)] cm plant height, [17.62 (2022-23), 17.86 (2023-24) and 17.74 (Pooled)] number of leaves per plant, [66.21 (2022-23), 68.45 (2023-24) and 67.33 (Pooled)] cm² leaf area, [5.27 (2022-23), 5.59 (2023-24) and 5.43 (Pooled)] number of runners per plant, [22.02 (2022-23), 22.33 (2023-24) and 22.19 (Pooled)] number of flower per plant, [71.13 (2022-23), 72.64 (2023-24) and 71.89 (Pooled)] % percentage of fruit setting (%) and [67.06 (2022-23), 69.07 (2023-24) and 68.07 (Pooled)] days taken to harvesting maturity.

Keywords: Growth; nano urea; RDN; strawberry; urea; winter dawn.

1. INTRODUCTION

The strawberry (*Fragaria x ananassa* Duch.) is a widely recognised fruit that originated approximately 250 years ago (Wilhelm and Sagen, 1972) and is consumed globally in both fresh and processed forms (Terefe et al., 2013). The presence of the letter “x” within the botanical name signifies that the strawberry is a result of hybridisation between two species, specifically *Fragaria virginiana* and *Fragaria chiloensis* (Panico et al., 2009). Notably, the heart shape and red colour of these strawberries have led to their association as symbols of Venus and the Goddess of Love (Rapuru et al., 2022).

FAOSTAT (2021) reports that the leading five producing countries globally are the People’s Republic of China with a production of 2,964,263 tonnes, followed by the United States of America at 1,296,272 tonnes, Mexico at 653,639 tonnes, Turkey at 440,968 tonnes, and Egypt at 362,639 tonnes (Altas Big, 2018-2021). In India, cultivation occurs over an area of 3,000 hectares, yielding an annual output of 14,000 metric tonnes (NHB 2021). Haryana leads as the largest producer with 1,650 metric tonnes, followed by Mizoram at 1,080 metric tonnes, and other contributors include Meghalaya, Maharashtra, and Himachal Pradesh (Anonymous, 2019). The agroclimatic conditions in Uttar Pradesh are conducive to strawberry production, presenting an opportunity for a profitable crop.

This herbaceous perennial plant is characterised by its short height, brief reproductive cycle, and straightforward vegetative propagation (Andres et al., 2022). The flowers are white and are pollinated by either wind or bees. The fruits, classified as false fruits, exhibit a red colouration upon ripening and originate from the development of the flower receptacle (Michel et al., 1981). Their composition includes fat-soluble vitamins such as A, E, and K, with particularly

high levels of vitamin C at 60 mg·100g⁻¹ of fresh fruit, vitamin B₉ (folate) at 24 µg·100g⁻¹ of fresh fruit, and vitamin E. The composition includes 89.9% water, 8.4% carbohydrates, 1.3% fibre, 0.7% protein, 0.5% fat, and 0.5% ash. Additionally, it contains 164 mg of potassium, 21 mg of calcium, 1.0 mg of sodium, 1.0 mg of iron, 60 I.U of thiamin, 0.07 mg of riboflavin, and 0.6 mg of niacin (Considine, 1982).

For successful strawberry cultivation, proper nitrogen management is crucial for quality growth and yields. Nitrogen (N) is identified as the most critical macro nutrient for enhancing crop growth and yield, as noted by Luo et al. (2018). The synthesis of chlorophyll, a critical component in the photosynthetic process, is predominantly influenced by nitrogen (N). This positions nitrogen as one of the most vital elements in plants, following carbon, hydrogen, and oxygen (Noor et al., 2023).

Fertilizers represent a considerable share of agricultural expenses, and their manufacturing utilizes a notable percentage of the energy required for horticultural practices (Shukla et al., 2022). The nitrogen use efficiency (NUE) in crops is observed to be significantly low when compared to the quantities of nitrogen applied to the soil (Govindasamy et al., 2023). Conventional fertilizers, specifically plant nutrient formulations with particle sizes exceeding 100 nm, result in a nitrogen loss ranging from 50 to 70%. This loss occurs primarily through leaching, where nitrogen is released as H₂O soluble nitrates, and through the emission of gaseous ammonia (Duhan et al., 2017).

Thus, Nanotechnology represents a developing area of research focused on the synthesis of minute materials, such as nanofertilizers (Albrecht et al., 2006). Norio Taniguchi, a professor at Tokyo University of Science, first introduced the term 'nanotechnology' in 1974

(Khan and Rizvi, 2014). Encapsulating fertilizer within nanoparticles can improve nutrient uptake efficiency (Subraya et al., 2015). Nano-fertilizers are engineered to deliver nutrients in a regulated fashion, tailored to meet the precise requirements of the crop (Derosa et al., 2010).

The incorporation of nanotechnology in agriculture, particularly via the formulation of nano urea, represents a significant advancement. Nano-urea has been developed and patented by the Indian Farmers Fertilizer Cooperative (IFFCO). This nano-urea, characterized by particle sizes within 20 and 80 nm, demonstrates an extended shelf-life, with a minimum of 50% of the particles measuring one nanometer. It contains 4% nitrogen (N) and exhibits a zeta potential exceeding 30 (Kumar et al., 2021). The implementation of nano-urea presents potential benefits for sustainable agricultural practices by decreasing the reliance on agro-chemicals, mitigating environmental pollution, and improving soil health (Mahapatra et al., 2022).

Nano urea offers an efficient method for nutrient delivery, potentially leading to enhanced growth. Considering this, the present study titled "Effect of Different Level of Nano Urea on Growth of Strawberry (*Fragaria X ananassa*) cv. Winter Dawn, under Prayagraj Agro Climatic Condition" was structured and carried out.

2. MATERIALS AND METHODS

The field study was conducted during the academic years 2022-23 and 2023-24, specifically from October through March. The strawberry cultivar Winter Dawn (runners) was sourced from Joshi Plants Enterprise, situated in Solan, Himachal Pradesh. The plot was prepared to attain a fine tilth by employing a series of repeated ploughing and planking processes. Weeds, grasses, and plant residues were eliminated, and raised beds were constructed for the purpose of planting. The beds were subsequently covered with silver-black polythene sheets to manage weed growth effectively. Tissue-cultured plants received fungicide treatment prior to field planting, arranged at a spacing of 60 cm by 30 cm. FYM at a rate of 25 tons per hectare was applied two weeks before the planting of the strawberry plantlets. The recommended fertiliser dosage, specifically NPK in a ratio of 100:60:40, was applied in accordance with the designated treatment combinations. The complete dosage of phosphorus (P) and potassium (K) was

administered via single super phosphate (SSP) and muriate of potash (MOP) as a basal application during the field preparation phase. A half dose of nitrogen was applied as a basal dose through Urea, while the remaining half was applied according to treatment combinations at 45 days post-transplanting. The application of water-soluble IFFCO Nano Urea (Liquid) was conducted three times in accordance with the treatment combination, specifically at the time of transplanting, and again at 20 and 40 days post-transplanting.

The experiment was carried out at the Horticulture Research Farm within the Department of Horticulture at Sam Higginbottom University of Agriculture, Technology, and Sciences located in Allahabad. The experimental site is situated on the left side of the Allahabad-Rewa Road, in proximity to the Yamuna River, approximately 8 kilometers from the city of Allahabad. The coordinates are 25.57°N latitude and 81.51°E longitude.

The experimental field demonstrated a sandy loam texture in its soil composition, with recorded pH levels of 6.3 and 6.0 for the years 2022-23 and 2023-24, respectively, indicating a neutral acidity level. The sample demonstrated organic carbon concentrations of 0.20% and 0.21%, while available nitrogen was quantified at 173.18 kg N/ha and 175.14 kg N/ha. The analysis revealed low concentrations of available phosphorus, quantified at 13.80 and 14.38 kg P/ha, alongside elevated concentrations of available potassium, documented at 216.40 and 219.34 kg K/ha. The crop accumulated a total of 13.86 mm and 10.02 mm of rainfall over the course of the experiment during both years of the study.

The experiment consisted eleven treatments viz. T₁: 100% RDF (NPK @ 100-60-140 kg/ha), T₂: 100% PK + 10% RDN + 1.8% Nano urea (18 ml/l), T₃: 100% PK + 20% RDN + 1.6% Nano urea (16 ml/l), T₄: 100% PK + 30% RDN + 1.4% Nano urea (14 ml/l), T₅: 100% PK + 40% RDN + 1.2% Nano urea (12 ml/l), T₆: 100% PK + 50% RDN + 1.0% Nano urea (10 ml/l), T₇: 100% PK + 60% RDN + 0.8% Nano urea (8 ml/l), T₈: 100% PK + 70% RDN + 0.6% Nano urea (6 ml/l), T₉: 100% PK + 80% RDN + 0.4% Nano urea (4 ml/l), T₁₀: 100% PK + 90% RDN + 0.2% Nano urea (2 ml/l) and T₁₁: 100% PK + 2% Nano urea (20 ml/l) which was analyzed in randomized block design with three replications.

The experiment was designed using a Randomised Block Design (Panse and

Sukhatme, 1985) with three replications for each of the eleven treatment combinations. Growth attributes like Days taken to new growth, Days to runner formation after planting, Plant height (cm), Number of leaves per plant, Leaf area (cm²), Number of runner per plant, No. of flower per plant, Percentage of fruit setting (%) and Days taken to harvesting maturity were successfully taken.

3. RESULTS

The statistical analysis focused on the growth attributes of strawberry (*Fragaria x ananassa*) cv. Winter Dawn. The results indicate that the integration of multiple treatments markedly improved all characteristics significantly. Given that F Cal exceeds F Tab, the data suggests that the variances are statistically significant.

3.1 Growth Attributes

Days taken to new growth: According to the above results (Table 1) the variances were found to be significantly different. Treatment T₇ [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] recorded minimum days to new growth [9.78 (2022-23), 10.05 (2023-24) and 9.91 (Pooled)] days whereas maximum days to new growth i.e., [16.45 (2022-23), 16.81 (2023-24) and 16.63

(Pooled)] days was found to be under the effect of treatment T₁₁ [100% PK + 2% Nano urea (20 ml/l)] during both the years of study as well as pooled data.

Days to runner formation after planting: According to data pertaining to Table 1, it was observed that the treatment T₇ [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] recorded the minimum days to runner formation after planting [31.11 (2022-23), 32.32 (2023-24) and 31.71 (Pooled)] days whereas maximum days to runner formation after planting i.e., [48.11 (2022-23), 49.86 (2023-24) and 48.99 (Pooled)] days was found to be under the effect of treatment T₁₁ [100% PK + 2% Nano urea (20 ml/l)] during 2022-23, 2023-24 and pooled basis.

Plant height (cm): The variances in plant height (cm) (Table 2) due to effect of different treatments was found to be significant during both the years of study as well as pooled basis. The highest plant height i.e., [17.11 (2022-23), 17.79 (2023-24) and 17.45 (Pooled)] cm was found under the effect of treatment T₇ [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)]. However, lowest plant height i.e., [14.00 (2022-23), 14.31 (2023-24) and 14.16 (Pooled)] cm was found to be under the effect of treatment T₁₁ [100% PK + 2% Nano urea (20 ml/l)].

Table 1. Effect of different level of nano urea on days taken to new growth and days to runner formation after planting of strawberry (*Fragaria x ananassa*) cv. winter dawn

Treatments	Days taken to new growth			Days to runner formation after planting		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T ₁	13.89	14.28	14.08	40.81	42.39	41.6
T ₂	16.01	16.46	16.23	46.29	48.07	47.18
T ₃	15.05	15.47	15.26	44.21	45.92	45.07
T ₄	14.72	15.13	14.93	43.12	44.78	43.95
T ₅	11.06	11.37	11.21	33.7	35.01	34.35
T ₆	10.43	10.72	10.58	32.39	33.64	33.01
T ₇	9.78	10.05	9.91	31.11	32.32	31.71
T ₈	12.05	12.39	12.22	36.15	37.54	36.84
T ₉	12.5	12.85	12.67	37.31	38.75	38.03
T ₁₀	12.92	13.28	13.1	38.49	39.97	39.23
T ₁₁	16.45	16.81	16.63	48.11	49.86	48.99
F-Test	S	S	S	S	S	S
S.E. (m) (±)	0.52	0.5	0.36	1.13	1.24	0.84
CD (5%)	1.55	1.48	1.04	3.34	3.67	2.41
CD (1%)	2.11	2.01	1.39	4.56	5.01	3.22

T₁: 100% RDF (NPK @ 100-60-140 kg/ha), T₂: 100% PK + 10% RDN + 1.8% Nano urea (18 ml/l), T₃: 100% PK + 20% RDN + 1.6% Nano urea (16 ml/l), T₄: 100% PK + 30% RDN + 1.4% Nano urea (14 ml/l), T₅: 100% PK + 40% RDN + 1.2% Nano urea (12 ml/l), T₆: 100% PK + 50% RDN + 1.0% Nano urea (10 ml/l), T₇: 100% PK + 60% RDN + 0.8% Nano urea (8 ml/l), T₈: 100% PK + 70% RDN + 0.6% Nano urea (6 ml/l), T₉: 100% PK + 80% RDN + 0.4% Nano urea (4 ml/l), T₁₀: 100% PK + 90% RDN + 0.2% Nano urea (2 ml/l) & T₁₁: 100% PK + 2% Nano urea (20 ml/l)

Table 2. Effect of different level of nano urea on plant height (cm) and number of leaves per plant of strawberry (*Fragaria x ananassa*) cv. winter dawn

Treatments	Plant height (cm)			Number of leaves per plant		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T ₁	15.08	15.68	15.38	15.53	15.74	15.64
T ₂	14.9	15.5	15.2	15.35	15.55	15.45
T ₃	15.37	15.99	15.68	15.83	16.04	15.94
T ₄	15.65	16.28	15.97	16.12	16.33	16.23
T ₅	16.47	17.13	16.8	16.96	17.19	17.08
T ₆	16.8	17.47	17.14	17.3	17.54	17.42
T ₇	17.11	17.79	17.45	17.62	17.86	17.74
T ₈	15.98	16.62	16.3	16.46	16.68	16.57
T ₉	15.75	16.38	16.07	16.22	16.44	16.33
T ₁₀	15.55	16.17	15.86	16.02	16.23	16.12
T ₁₁	14	14.31	14.16	14.24	14.37	14.31
F-Test	S	S	S	S	S	S
S.E. (m) (±)	0.28	0.37	0.23	0.3	0.36	0.23
CD (5%)	0.83	1.08	0.66	0.89	1.06	0.67
CD (1%)	1.14	1.47	0.88	1.21	1.44	0.89

T₁: 100% RDF (NPK @ 100-60-140 kg/ha), T₂: 100% PK + 10% RDN + 1.8% Nano urea (18 ml/l), T₃: 100% PK + 20% RDN + 1.6% Nano urea (16 ml/l), T₄: 100% PK + 30% RDN + 1.4% Nano urea (14 ml/l), T₅: 100% PK + 40% RDN + 1.2% Nano urea (12 ml/l), T₆: 100% PK + 50% RDN + 1.0% Nano urea (10 ml/l), T₇: 100% PK + 60% RDN + 0.8% Nano urea (8 ml/l), T₈: 100% PK + 70% RDN + 0.6% Nano urea (6 ml/l), T₉: 100% PK + 80% RDN + 0.4% Nano urea (4 ml/l), T₁₀: 100% PK + 90% RDN + 0.2% Nano urea (2 ml/l) & T₁₁: 100% PK + 2% Nano urea (20 ml/l)

Table 3. Effect of different level of nano urea on leaf area (cm²) and number of runners per plant of strawberry (*Fragaria x ananassa*) cv. winter dawn

Treatments	Leaf area (cm ²)			Number of runners per plant		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T ₁	53.9	55.73	54.82	4.36	4.62	4.49
T ₂	47.24	48.83	48.03	3.77	4	3.88
T ₃	49.82	51.51	50.67	4	4.24	4.12
T ₄	51.12	52.85	51.98	4.11	4.36	4.23
T ₅	63.08	65.22	64.15	5	5.3	5.15
T ₆	64.67	66.85	65.76	5.15	5.46	5.3
T ₇	66.21	68.45	67.33	5.27	5.59	5.43
T ₈	60.02	62.05	61.03	4.83	5.12	4.97
T ₉	58.48	60.46	59.47	4.72	5	4.86
T ₁₀	56.92	58.84	57.88	4.6	4.88	4.74
T ₁₁	45.12	46	45.56	3.5	3.64	3.57
F-Test	S	S	S	S	S	S
S.E. (m) (±)	1.29	1.47	0.98	0.11	0.12	0.08
CD (5%)	3.82	4.33	2.8	0.32	0.36	0.23
CD (1%)	5.21	5.9	3.74	0.43	0.49	0.31

T₁: 100% RDF (NPK @ 100-60-140 kg/ha), T₂: 100% PK + 10% RDN + 1.8% Nano urea (18 ml/l), T₃: 100% PK + 20% RDN + 1.6% Nano urea (16 ml/l), T₄: 100% PK + 30% RDN + 1.4% Nano urea (14 ml/l), T₅: 100% PK + 40% RDN + 1.2% Nano urea (12 ml/l), T₆: 100% PK + 50% RDN + 1.0% Nano urea (10 ml/l), T₇: 100% PK + 60% RDN + 0.8% Nano urea (8 ml/l), T₈: 100% PK + 70% RDN + 0.6% Nano urea (6 ml/l), T₉: 100% PK + 80% RDN + 0.4% Nano urea (4 ml/l), T₁₀: 100% PK + 90% RDN + 0.2% Nano urea (2 ml/l) & T₁₁: 100% PK + 2% Nano urea (20 ml/l)

Number of leaves per plant: The data pertaining to number of leaves per plant (Table 2) shows that significant variances were found due to application of different treatments. Treatment T₇ [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] recorded the maximum number of leaves per plant [17.62 (2022-23), 17.86 (2023-24) and 17.74 (Pooled)] whereas minimum number of leaves per plant i.e., [14.24 (2022-23), 14.37 (2023-24) and 14.31 (Pooled)]

was found to be under the effect of treatment T₁₁ [100% PK + 2% Nano urea (20 ml/l)] during 2022-23, 2023-24 and pooled basis.

Leaf area (cm²): According to the results (Table 3) the differences in leaf area (cm²) were found significant. According to the findings, treatment T₇ [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] was found with maximum leaf area (cm²) [66.21 (2022-23), 68.45 (2023-24) and 67.33 (Pooled)] cm² whereas minimum leaf area (cm²) i.e., [45.12 (2022-23), 46.00 (2023-24) and 45.56 (Pooled)] cm² was found to be under the effect of treatment T₁₁ [100% PK + 2% Nano urea (20 ml/l)] during both the years of study as well as pooled data.

Number of runners per plant: Data pertaining to Table 3, observed that the treatment T₇ [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] recorded the maximum number of runners per plant [5.27 (2022-23), 5.59 (2023-24) and 5.43 (Pooled)] whereas minimum number of runner per plant i.e., [3.50 (2022-23), 3.64 (2023-24) and 3.57 (Pooled)] was found to be under the effect of treatment T₁₁ [100% PK + 2% Nano urea (20 ml/l)] during 2022-23, 2023-24 and pooled basis.

Number of flower per plant: The variances in number of flower per plant (Table 4) due to effect of different treatments was found to be significant during both the years of study as well as pooled basis. The maximum number of flower per plant [22.02 (2022-23), 22.33 (2023-24) and 22.19 (Pooled)] was found under the effect of treatment T₇ [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)]. However, minimum number of flower per plant i.e., [15.45 (2022-23), 15.60 (2023-24) and 15.53 (Pooled)] was found to be under the effect of treatment T₁₁ [100% PK + 2% Nano urea (20 ml/l)].

Percentage of fruit setting (%): The data pertaining to percentage of fruit setting (%) (Table 4) shows that significant variances were found due to application of different treatments. Treatment T₇ [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] recorded the highest percentage of fruit setting (%) [71.13 (2022-23), 72.64 (2023-24) and 71.89 (Pooled)] % whereas lowest percentage of fruit setting (%) i.e., [69.17 (2022-23), 70.00 (2023-24) and 69.58 (Pooled)] % was found to be under the effect of treatment T₁₁ [100% PK + 2% Nano urea (20 ml/l)] during 2022-23, 2023-24 and pooled basis.

Table 4. Effect of different level of nano urea on number of flower per plant and percentage of fruit setting (%) of strawberry (*Fragaria x ananassa*) cv. winter dawn

Treatments	Number of flower per plant			Percentage of fruit setting (%)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T ₁	18.7	18.94	18.82	70.08	71.47	70.77
T ₂	16.59	16.81	16.7	69.42	70.73	70.08
T ₃	17.4	17.62	17.51	69.69	71.04	70.36
T ₄	17.85	18.08	17.97	69.85	71.21	70.53
T ₅	21.15	21.42	21.29	70.7	72.17	71.44
T ₆	21.5	21.78	21.64	70.93	72.42	71.67
T ₇	22.05	22.33	22.19	71.13	72.64	71.89
T ₈	20.3	20.56	20.43	70.43	71.86	71.15
T ₉	19.97	20.23	20.1	70.39	71.82	71.1
T ₁₀	19.58	19.83	19.71	70.32	71.74	71.03
T ₁₁	15.45	15.6	15.53	69.17	70	69.58
F-Test	S	S	S	S	S	S
S.E. (m) (±)	0.33	0.36	0.24	0.32	0.38	0.25
CD (5%)	0.98	1.06	0.7	0.93	1.11	0.7
CD (1%)	1.33	1.45	0.94	1.27	1.51	0.94

T₁: 100% RDF (NPK @ 100-60-140 kg/ha), T₂: 100% PK + 10% RDN + 1.8% Nano urea (18 ml/l), T₃: 100% PK + 20% RDN + 1.6% Nano urea (16 ml/l), T₄: 100% PK + 30% RDN + 1.4% Nano urea (14 ml/l), T₅: 100% PK + 40% RDN + 1.2% Nano urea (12 ml/l), T₆: 100% PK + 50% RDN + 1.0% Nano urea (10 ml/l), T₇: 100% PK + 60% RDN + 0.8% Nano urea (8 ml/l), T₈: 100% PK + 70% RDN + 0.6% Nano urea (6 ml/l), T₉: 100% PK + 80% RDN + 0.4% Nano urea (4 ml/l), T₁₀: 100% PK + 90% RDN + 0.2% Nano urea (2 ml/l) & T₁₁: 100% PK + 2% Nano urea (20 ml/l)

Table 5. Effect of different level of nano urea on leaf area (cm²) and number of runners per plant of strawberry (*Fragaria x ananassa*) cv. winter dawn

Treatments	Days taken to harvesting maturity		
	2022-23	2023-24	Pooled
T ₁	73.24	75.44	74.34
T ₂	76.94	79.25	78.1
T ₃	75.44	77.7	76.57
T ₄	74.75	76.99	75.87
T ₅	68.8	70.86	69.83
T ₆	67.94	69.98	68.96
T ₇	67.06	69.07	68.07
T ₈	70.33	72.44	71.39
T ₉	71.05	73.18	72.12
T ₁₀	71.74	73.89	72.82
T ₁₁	78	79.88	78.94
F-Test	S	S	S
S.E. (m) (±)	0.83	1.05	0.67
CD (5%)	2.46	3.09	1.92
CD (1%)	3.36	4.22	2.56

T₁: 100% RDF (NPK @ 100-60-140 kg/ha), T₂: 100% PK + 10% RDN + 1.8% Nano urea (18 ml/l), T₃: 100% PK + 20% RDN + 1.6% Nano urea (16 ml/l), T₄: 100% PK + 30% RDN + 1.4% Nano urea (14 ml/l), T₅: 100% PK + 40% RDN + 1.2% Nano urea (12 ml/l), T₆: 100% PK + 50% RDN + 1.0% Nano urea (10 ml/l), T₇: 100% PK + 60% RDN + 0.8% Nano urea (8 ml/l), T₈: 100% PK + 70% RDN + 0.6% Nano urea (6 ml/l), T₉: 100% PK + 80% RDN + 0.4% Nano urea (4 ml/l), T₁₀: 100% PK + 90% RDN + 0.2% Nano urea (2 ml/l) & T₁₁: 100% PK + 2% Nano urea (20 ml/l)

Days taken to harvesting maturity: Data pertaining to Table 5, observed that the treatment T₇ [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] recorded the minimum days taken to harvesting maturity [67.06 (2022-23), 69.07 (2023-24) and 68.07 (Pooled)] days whereas maximum days taken to harvesting maturity i.e., [78.00 (2022-23), 79.88 (2023-24) and 78.94 (Pooled)] days was found to be under the effect of treatment T₁₁ [100% PK + 2% Nano urea (20 ml/l)] during 2022-23, 2023-24 and pooled basis.

4. DISCUSSION

All treatments demonstrated significant effects on the growth characteristics of strawberry. However, treatment T₇ [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] was identified as the most effective.

Nitrogen is an essential nutrient necessary for the synthesis of amino acids and proteins, which are crucial for the growth and development of plants (Fathi, 2022). The nanoscale properties of nano urea improve the efficiency of urea absorption in plants. This procedure facilitates a more effective nitrogen release mechanism, consequently enhancing nitrogen availability to the plant over an extended period (Agehara,

2021). The slow-release characteristic of nano urea contributes to maintaining optimal nitrogen levels in the soil, thereby addressing common issues associated with conventional nitrogen fertilizers, such as leaching and volatility (Shaifali et al., 2023). The balanced supply supports strawberry plants in alleviating initial stress conditions experienced during transplanting or seasonal changes, thus promoting the earlier initiation of new growth cycles, potentially resulting in reduced days to new growth and earlier days to runner formation post-planting (Zhang et al., 2023). Researchs also indicate that nano urea improves nutrient absorption by as much as 30%, thereby facilitating accelerated metabolic processes essential leading to swift transformation of nutrients into biomass and then into fruit, thereby decreasing the total time required for maturity resulting in early days taken to harvesting maturity (Shareef et al., 2020). Beniwal et al. (2024), Khalil et al. (2022), Singh et al. (2023) and Yadav et al. (2024) found similar results while working on strawberry.

Increased plant height (cm) and leaf area (cm²) with different nitrogen management practices might be attributed to synergistic effects of nitrogen supplied through conventional urea and the advanced properties of nano urea, for the early establishment for photosynthetic devices

such as enzymes, pigments and other compounds (Sun et al., 2023). The small particle size of nano urea also facilitates enhanced penetration into plant tissues, promoting increased plant height and larger leaf areas while mitigating the nitrogen loss commonly associated with traditional urea applications (Jakhar et al., 2022). Yassin et al. (2023) while working on strawberry found similar results.

Nano-fertilizers are essential for enhancing the physiological and biochemical processes in crops, results in improved metabolic processes and encourages meristematic activities, resulting in greater apical growth and an expanded photosynthetic area (Devi et al., 2023). The application of nano urea through foliar routes led to an enhancement in nitrogen uptake in both leaf and root systems. The observed increase likely facilitated a higher conversion rate of synthesized carbohydrates into amino acids and proteins. This process subsequently accelerated cell division and elongation, resulting in an increase in leaf number (Dhayalan et al., 2023). The improved nitrogen absorption also facilitates the synthesis of proteins, amino acids, and chlorophyll, which are essential for robust vegetative growth and runner development (De and Das, 2024). Bhatti et al. (2023) and Singh et al. (2023) in guava and Kalil et al. (2022) in strawberry found similar results.

Nitrogen is also essential for flowering, as it facilitates the production of crucial growth hormones and enzymes that are integral to reproductive development (Huang et al., 2024). The gradual release of nano urea ensures consistent nitrogen availability, which minimises nitrogen stress and promotes optimal conditions for flower initiation and development leading to increased number of flowers per plant (Iqbal et al., 2019). The enhanced availability of nitrogen through nano urea also has a direct effect on fruit setting by increasing photosynthetic activity, thereby providing the necessary energy to facilitate the development of viable flowers and achieve increased percentage of fruit set (%) (Kumar et al., 2023). Comparable findings have been documented by Hashemabadi et al. (2019) in the context of strawberries and by Bhatti et al. (2023) concerning guavas.

5. CONCLUSION

From the present investigation it may be concluded that effect of Treatment T₇ [100% PK + 60% RDN + 0.8% Nano urea (8 ml/l)] was

found to be best. It is best in terms of growth attributes i.e., Days taken to new growth, Days to runner formation after planting, Plant height (cm), Number of leaves per plant, Leaf area (cm²), Number of runner per plant, No. of flower per plant, Percentage of fruit setting (%) and Days taken to harvesting maturity.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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