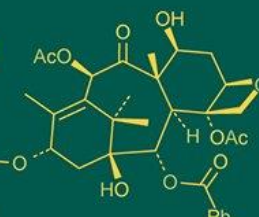
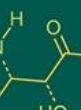
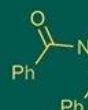


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(8): 1729-1733
www.biochemjournal.com
Received: 25-06-2026
Accepted: 30-07-2026

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Effect of nano-urea, urea and NAA on growth and yield attributes of acid lime (*Citrus aurantifolia*) cv. Kagzi

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i8Ss.9658>

Abstract

Acid lime (*Citrus aurantifolia* Swingle), a key citrus crop in India, is valued for its nutritional and medicinal benefits, including high vitamin C, antioxidants, and citric acid. Cultivation practices significantly impact productivity and quality, with balanced fertilization and innovative nutrient delivery being crucial. The study examined the effects of foliar applications of conventional urea, nano-urea, and NAA (naphthalene acetic acid) on the growth, yield, and quality of acid lime cv. Kagzi. Conducted during 2021-2022 in Madhya Pradesh, the experiment involved seven treatments and recorded parameters such as flowering, fruit set, and yield. Results highlighted that nano-urea (0.4%) outperformed conventional fertilizers, improving flowering, hermaphrodite flower ratios, fruit set percentage, and yield while reducing fruit drop. Maximum fruit set (59.81%) was achieved with NAA (20 ppm). Nano-urea treatments also demonstrated increased nutrient efficiency, reducing the environmental impacts of traditional fertilizers. The findings support nano-fertilizers and bio-regulators as effective strategies to enhance productivity and sustainability in acid lime cultivation.

Keywords: Acid lime, *Citrus aurantifolia*, foliar application, fruit quality, growth, nano-urea, NAA, urea, yield

Introduction

Acid lime (*Citrus aurantifolia* Swingle) ranks as India's third most significant citrus crop, following mandarins and sweet oranges. Belonging to the Rutaceae family (chromosome number $2n = 18$), this primarily subtropical fruit is also adaptable to tropical cultivation. The fruit is characterized by its small, round or oval shape, polyembryonic nature, greenish-yellow flesh, high juice content, pronounced acidity, and distinct aroma. Valued for its nutritional and medicinal properties, acid lime juice is rich in sugars, fruit acids (particularly citric acid), vitamin C, and antioxidants (Thiruganavel *et al.*, 2007; Prasad and Kumar, 2012) [22, 16]. Nutritional analysis indicates that 100 g of juice typically contains approximately 80g water, 26 IU vitamin A (as carotene), 20 mg vitamin B1, 0.1mg riboflavin, 63mg vitamin C, 1.83 mg iron, and 0.16 mg copper, underscoring its health benefits.

Acid lime plants exhibit a medium height, bushy and vigorous growth habit with spreading branches. Their dense foliage consists of small, pale green, broadly lanceolate leaves. The trees typically flower three times annually: Ambia/Ambe bahar (January-February), Mrig Bahar (June-July), and Hasta bahar (September-October). Recognized as a nutrient-demanding crop, the productivity and juice quality of acid lime are directly influenced by nutrient supply. While balanced fertilization is essential for enhancing yield and maintaining fruit quality, the excessive and imbalanced use of chemical fertilizers poses risks, including environmental damage, soil degradation, and ultimately, reduced fruit quality and productivity, impacting human health. Consequently, identifying effective nutrient management strategies is crucial to maximize productivity and nutrient use efficiency while safeguarding environmental health. One promising approach involves reducing application rates, especially for highly mobile nutrients like nitrogen, and enhancing their effectiveness.

In this context, nano-fertilizers, particularly nano-urea, have emerged as a viable commercial alternative. Studies report that foliar nano-urea application in fruit crops can reduce conventional urea requirements by up to 50% while boosting use efficiency to approximately 90%.

Furthermore, plant growth regulators (PGRs or bio-regulators) represent another vital strategy for improving fruit productivity and quality. They achieve this by enhancing flowering, fruit set, fruit size, and shape, while also reducing fruit drop. Considering these factors, the present investigation was undertaken to develop protocols for nitrogen application using both conventional urea and nano-urea—alongside PGR application (specifically NAA), aiming to optimize benefits in acid lime cultivation.

Materials and Methods

A field experiment was conducted during the 2021-2022 growing season at the Fruit Research Station, Imaliya, Department of Horticulture, JNKVV, Maharajpur (Madhya Pradesh), utilizing a well-established orchard of Kagzi acid lime (*Citrus aurantifolia* Swingle). The study employed 28 uniformly spaced plants (6 × 6 m) in a randomized layout. Seven foliar spray treatments were evaluated: T₁: Control (water spray); T₂: 2.0% urea; T₃: 4.0% urea; T₄: 0.2% nano-urea; T₅: 0.4% nano-urea; T₆: 20 ppm NAA (naphthalene acetic acid); T₇: 40 ppm NAA. Treatments were applied twice: first at the 50% flowering stage and second post-fruit set, ensuring precise physiological timing. The experimental soil was characterized as clay-loam with traces of heavy clay, representative of regional growing conditions. The primary objective was to assess the impact of conventional urea, nano-urea, and the growth regulator NAA on growth attributes (e.g., vegetative development, floral metrics) and yield parameters (e.g., fruit set, fruit number, yield efficiency) of Kagzi lime. Data collected throughout the trial were rigorously analyzed using Analysis of Variance (ANOVA). The significance of treatment effects was determined via the F-test at a 5% probability level ($p \leq 0.05$). Where ANOVA indicated significant differences, mean comparisons were made using the Critical Difference (CD) to identify statistically distinct treatments. This design ensured robust evaluation of nano-technology and bioregulators as sustainable alternatives to conventional nitrogen fertilization for enhancing acid lime productivity.

Results and Discussion

Floral bud initiation

The data pertaining to floral bud initiation is presented in Table 4.1. The data revealed that the flower bud initiation ranged from 5th January to 15th January and it was recorded that earlier (5th January) flower bud initiation took place under T₆, while it was delayed (15th January) in T₁ (control).

Days to 50% flowering

The data representing days to 50% flowering is presented in Table 1. The data revealed that days to 50% flowering ranged from 27 to 35 days and it was observed that among the different treatments, minimum (27) days were required under T₆ to attain 50% flowering while maximum (35 days) number of days were recorded in T₁ (control).

Number of flowers shoot⁻¹

Data clearly showed that number of flowers shoot⁻¹ was significantly influenced by the treatments. Maximum numbers of flowers shoot⁻¹ (50.93) was obtained under treatment T₅ (spray of 0.4% Nano-urea) over rest of the treatments excluding T₂ (46.95), T₃ (49.67) and T₄ (48.21) which were statistically at par with treatment T₅. However, the minimum number of flowers shoot⁻¹ (43.15) was recorded under control having no applied nutrients.

Number of flowers tree⁻¹

It is clear from the data that the maximum number of flowers tree⁻¹ (1986) was observed with application of Nano-urea (0.4%) over all the treatments including control which was found to be at par with treatment T₃ (1887) and T₄ (1832). However, the minimum number of flowers tree⁻¹ (1553) was found under control (T₁).

Hermaphrodite flower (%)

The results revealed that the hermaphrodite flower (%) was influenced significantly by the treatments. It was observed that the higher hermaphrodite flower% (88.93%) was recorded in T₅ with application of Nano-urea (0.4%) while, the minimum percentage of hermaphrodite flower was recorded in T₁ (Control) i.e., 76.39%.

Male flower (%)

The minimum male flower% (11.07%) was recorded with application of Nano-urea (0.4%) which was found to be at par with T₃ (12.75%). However maximum male flower percentage (23.61%) was recorded under control (T₁).

Hermaphrodite: Male ratio

The higher ratio of Hermaphrodite (8.03) was recorded under the foliar application of Nano-Urea (0.4%) and lower ratio (3.24) was recorded under control.

Days to initial fruit set

It is clear from the data that the minimum number of days (5.87) to initial fruit set from 50% flowering was observed under treatment T₅ (foliar spray of Nano-urea @ 0.4%) followed by T₃ (6.02) whereas the maximum days (8.15) to initial fruit set was found under control T₁.

Yield parameters

Fruit set%

It is clear from the data that the fruit set% was significantly influenced by different treatments. The result revealed that the maximum number of fruit set% (59.81%) was observed under the treatment T₆ with the application of 20 ppm NAA which was found to be significantly at par with treatment T₅ (57.95%) and T₇ (54.67%). The minimum number of fruits set% (45.13%) was noted under control T₁.

Fruit drop%

It was observed that fruit drop was significantly influenced by the spray of plant growth regulators. The result thus obtained showed that minimum (40.19%) fruit drop was recorded under the treatment T₆ (foliar application of 20 ppm NAA) while the maximum (54.87%) fruit drop% was recorded under control (T₁).

Table 1: Effect of Nano-urea, Urea and NAA on growth attributes of Acid lime (*Citrus aurantifolia*) cv. Kagzi.

Treatment	Date of flower bud initiation	Days to 50% flowering	Number of flowers shoot ⁻¹	Number of flowers tree ⁻¹	Hermaphrodite flower (%)	Male flower (%)	Hermaphrodite: Male flower	Days to initial fruit set
T ₁ -Control	15 th January	35	43.15	1553	76.39	23.61	3.24	8.15
T ₂ -Foliar spray of Urea @ 2%	12 th January	33.5	46.95	1737	83.27	16.73	4.98	7.46
T ₃ -Foliar spray of Urea @ 4%	10 th January	29.3	49.67	1887	87.25	12.75	6.84	6.02
T ₄ -Foliar spray of Nano-urea @ 0.2%	13 th January	31.8	48.21	1832	86.39	13.61	6.35	6.35
T ₅ -Foliar spray of Nano-urea @ 0.4%	11 th January	27.8	50.93	1986	88.93	11.07	8.03	5.87
T ₆ -Foliar spray of NAA @ 20 ppm	5 th January	28.3	45.71	1691	81.75	18.25	4.48	6.62
T ₇ -Foliar spray of NAA @ 30 ppm	8 th January	29.5	44.89	1661	78.81	21.19	3.72	7.84
SEm±			1.63	73	3.51	0.72	0.22	0.073
CD 5%			4.88	221	10.49	2.15	0.67	0.218

Number of fruit shoot⁻¹

The data indicate that the number of fruits shoot⁻¹ was significantly influenced by different treatments. The result revealed that the maximum number of fruit shoot⁻¹ (29.51) was observed under the treatment T₅ with the application of Nano-urea (0.4%) which was found to be at par with T₆ (28.83). The minimum number of fruits per shoot (18.81) found under control (T₁).

Number of fruits tree⁻¹

It is cleared from the data that with the application of Nano-urea (0.4%), maximum number of fruit tree⁻¹ (1151.04) was recorded in treatment T₅ which was found to be at par with treatment T₆ (1095.71) with foliar application of NAA 20 ppm. However, the minimum number of fruits per plant (677.00) was recorded under control (T₁).

Average fruit weight

The average fruit weight was recorded to be significant among different treatments. Maximum average weight of the fruit was observed in treatment T₃ (49.37 g) with foliar application of urea 4% followed by the treatment T₄ (47.55 g) and the minimum average fruit weight was found in treatment T₇ (41.77 g).

Fruit yield (kg) tree⁻¹

The results revealed that the maximum fruit yield tree⁻¹ (49.17) was recorded with the foliar spray of urea 2% under the treatment T₂ followed by treatment T₅ (48.79), T₆ (47.70)

which were found to be at par with T₂. However, the minimum fruit yield tree⁻¹ (29.73) was recorded under control.

Discussion**Effect of Nano-urea, Urea and NAA on growth and development attributes of Acid lime.**

It is evident from the data and the result presented in previous chapter that various treatments of different concentrations had significant effect on growth and development parameters such as number of flowers shoot⁻¹, total number of flower tree⁻¹, hermaphrodite flowers (%) and hermaphrodite: male ratio and days to initial fruit set. It might be because urea and Nano-urea play an important function in encouraging plant growth as nitrogen is a constituent of chlorophyll, the substance that allows plants to use sunlight energy to convert CO₂ to carbohydrates through the process of photosynthesis. Similar findings were done by Chermahini *et al.* 2011 [2] and Syamal *et al.*, 2008 [21] who revealed that the increase in number of flowers and hermaphrodite flowers may be due to the nitrogen which is major component of protoplasm which increase photosynthesis. The nitrogen supplied through Nano-urea helps in chlorophyll synthesis which increases photosynthesis as a result of which there is more accumulation of carbohydrates leading to flower initiation and profuse flowering. Similar findings also in conformity reported by Etehadnejad and Aboutalebi (2014) [5], Lovatt (1994) [10], Stiles (1999) [20].

Table 2: Effect of Nano-urea, Urea and NAA on yield attributes of Acid lime (*Citrus aurantifolia*) cv. Kagzi.

Treatment	Fruit set%	Fruit drop%	Number of fruits shoot ⁻¹	Number of fruits tree ⁻¹	Average weight of fruit (g)	Fruit yield per plant (kg)
T ₁ -Control	45.13	54.87	18.81	677	43.91	29.73
T ₂ -Foliar spray of Urea @ 2%	47.95	52.05	21.05	778.67	45.79	35.66
T ₃ -Foliar spray of Urea @ 4%	52.77	47.23	26.21	996.01	49.37	49.17
T ₄ -Foliar spray of Nano-urea @ 0.2%	49.51	50.49	22.63	837.35	47.55	39.82
T ₅ -Foliar spray of Nano-urea @ 0.4%	57.95	42.05	29.51	1151.04	42.39	48.79
T ₆ -Foliar spray of NAA @ 20 ppm	59.81	40.19	28.83	1095.71	43.53	47.7
T ₇ -Foliar spray of NAA @ 30 ppm	54.67	45.33	25.67	949.7	41.77	39.67
SEm±	2.29	1.86	0.98	41.41	1.64	1.92
CD 5%	6.82	5.55	2.92	123.05	4.88	5.72

Effect of Nano-urea, urea and NAA on yield and yield attributes of Acid Lime

Maximum fruit set% (59.81%) was recorded by the foliar spray of 20ppm NAA followed by foliar application of 0.4% Nano-urea (57.95%). However the minimum fruit set percentage was recorded under control (45.13%). It was also observed that the fruit drop percentage was minimum (40.19%) by the foliar application of 20ppm NAA while the

fruit drop% was registered highest (54.87) under control. It may be because administration of NAA maintains and sustains the various physiological as well as bio-chemical process of inhibiting abscission. Along with this NAA also improve the physiology of fruits which is important for their appropriate growth and development resulting in reduction of fruit drop and increasing fruit retention. Similar findings were done in ber by Rajpal *et al.*

Maximum number of fruits shoot⁻¹ (29.51) was observed by the foliar spray of Nano-urea (0.4%) which was found to be at par with foliar spray of 20 ppm NAA (28.83). The minimum number of fruits per shoot (18.81) was found under control. The results revealed that with the application of Nano-urea (0.4%), maximum number of fruit tree⁻¹ (1151.04) was recorded which was found to be at par with the foliar spray of 20 ppm NAA (1095.71). However, the minimum number of fruits tree⁻¹ (677.00) was recorded under control.

Same findings were done by Lovatt (1994)^[10], Stiles (1999)^[20]. They reported that the increase in number of fruits may be due to foliar application of nitrogen fertilizer. The metabolic and physiological roles of nitrogen includes supply of carbohydrates which are important and necessary for growth of flower bud, initiation of flower and its development, along with effective pollination and fertility. The foliar application of NAA had a significant effect on the retention of fruit which may be due to balancing the internal status of auxin which prevents the formation of abscission layer which leads to produce more numbers of fruits. Similar findings were also obtained by Singh and Rajput (1988)^[18] in mango.

Maximum average fruit weight (49.37 g) was observed with foliar application of urea 4% followed by the foliar spray of nano-urea @ 0.2% (47.55 g) and the minimum weight of fruit was found by the foliar spray of 30 ppm NAA (41.77 g). The increase in fruit weight by urea may be due to accumulation of sugars and high percentage of pulp. This finding was in accordance with the Mazumdar and Bhatt (1976)^[12] in sweet orange. Similar findings were done by Parmar *et al.* (2014)^[15] in guava.

It was also observed that the maximum fruit yield tree⁻¹ (49.17) was noted by the foliar spray of urea 2% followed by foliar spray of 0.4% Nano-urea (48.79), foliar spray of 20ppm NAA (47.70) which were statistically at par with T₂. Whereas, the minimum fruit yield tree⁻¹ (29.73) was obtained under control. This may be due to the cumulative effects of nitrogen on photosynthetic and metabolic activities which resulted in increase in fruit size and weight and therefore increasing yield of Acid lime (Jat and Kacha, 2014).

Conclusion

On the basis of result obtained in present experiment, it can be concluded that treatment T₅ (foliar spray of 0.4% nano-urea) was found significantly superior as compared to other treatments for growth and development parameter. Maximum fruit set% and minimum fruit drop% was observed with the foliar application of 20 ppm NAA. Maximum yield and yield attributing characters were found recorded under foliar spray of 4% urea and 0.4% nano urea

Acknowledgement

The author wishes to acknowledge the support and facilities provided by the Head of the Department of Horticulture at the College of agriculture Jabalpur to carry out the present investigation.

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