E-ISSN: 2663-1067
P-ISSN: 2663-1075
NAAS Rating: 4.74
www.hortijournal.com
IJHFS 2025; 7(6): 107-110
Received: 01-04-2025
Accepted: 04-05-2025

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Influence of nitrogenous fertilizers (Urea and nano urea) on primary nutrient content in tomato leaves and fruits

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DOI: https://www.doi.org/10.33545/26631067.2025.v7.i6b.327

Abstract
Tomato (*Solanum lycopersicum* L.) is a nutrient-intensive crop that requires efficient nitrogen management to achieve optimal growth and fruit quality. Traditional urea-based fertilizer, though widely used, suffers from low nitrogen use efficiency (NUE), resulting in substantial nutrient losses and environmental concerns. This study evaluated the influence of nano urea, a novel nitrogenous fertilizer, applied in combination with conventional urea under varying nitrogen regimes, on the primary nutrient content (N, P, K) in tomato leaves and fruits. Twelve fertilizer treatments were assessed, including full (100%), moderate (75%) and low (50%) recommended dose of nitrogen (RDN), applied through conventional urea and nano urea, at different growth stages. Results revealed that treatment T_4 comprising 100% RDN with 50% applied as basal dose and nano urea foliar sprays at both 30 and 45 days after transplanting (DAT) consistently recorded the highest nutrient content in leaves and fruits (N: 3.33% and 0.36%, P: 0.19% and 0.34%, K: 1.73% and 2.09%, respectively). Treatments combining nano and conventional urea (T_2 and T_3) also significantly improved nutrient uptake, while reduced nitrogen treatments (50% RDN) showed comparatively lower nutrient accumulation, even when supplemented with nano urea. The findings highlight that nano urea enhances NUE, nutrient uptake and fruit nutritional quality, especially when applied in conjunction with conventional nitrogen sources under optimal nitrogen regimes. While nano urea showed promise in partially mitigating nutrient deficiencies under reduced RDN, it could not fully substitute for conventional nitrogen. Thus, nano urea serves as an efficient complementary input in sustainable nutrient management strategies. Future research should focus on its long-term effects on crop productivity, soil health and economic viability under field conditions.

Keywords: Tomato, nano urea, nitrogen use efficiency, nutrient uptake, sustainable agriculture, fertilizer strategy

Introduction
Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops grown worldwide, valued for its nutritional, economic and dietary significance. It is a rich source of vitamins, antioxidants and minerals, making it a vital component of both subsistence and commercial agriculture. To achieve optimal growth and fruit quality, tomatoes have a high nutrient demand, particularly for nitrogen (N), which plays a crucial role in vegetative growth, chlorophyll synthesis and fruit development (Kumar *et al*., 2021) [5].
Nitrogen is traditionally supplied through conventional fertilizers such as urea. However, the low nitrogen use efficiency (NUE) of urea typically ranging between 30-50% leads to substantial losses through leaching, volatilization and denitrification, which not only reduces crop productivity but also contributes to environmental degradation (Adhikari *et al*., 2022; Bhardwaj *et al*., 2022) [4, 6]. Consequently, there is growing interest in alternative nitrogen delivery systems that can enhance NUE while minimizing environmental impact.
In recent years, nano-fertilizers, particularly nano urea, have emerged as innovative tools in sustainable nutrient management. Nano urea is a colloidal suspension of nitrogen particles synthesized at the nanoscale, typically less than 100nm, which offers unique advantages such as high surface area, enhanced foliar absorption and controlled nutrient release (Raliya *et al*., 2016; Chhipa, 2017) [1, 2]. These properties enable nano urea to increase nitrogen uptake efficiency and reduce the total fertilizer requirement without compromising yield or quality. Preliminary studies have reported promising outcomes of nano urea in improving growth,

nutrient uptake and productivity in crops such as wheat, maize and rice (Singh *et al*., 2021; Ramesh *et al*., 2021) [5]. However, empirical evidence regarding its effectiveness in horticultural crops, particularly tomato, remains limited. Moreover, the potential of combining nano urea with conventional nitrogen strategies under varying nitrogen regimes has not been fully explored. Understanding how such combinations influence the accumulation of primary nutrients (N, P and K) in vegetative and reproductive tissues can provide insights into optimizing fertilizer practices for better crop nutrition and environmental stewardship.

Therefore, the present study was undertaken to evaluate the influence of nano urea, in combination with conventional urea, on the nutrient content of tomato leaves and fruits under different nitrogen regimes. The objective was to assess whether nano urea can enhance nutrient uptake and reduce nitrogen input requirements, thereby offering a sustainable and efficient approach to tomato nutrition management.

Materials and Methods

This research investigation was carried out at the College of Horticulture Bagalkot, situated at 16º10' N latitude, 74º42' E longitude, and an elevation of 542 meters above sea level, spanning the period from 2022 to 2023. The location falls within the northern dry agro-climatic zone of Karnataka, characterized by an average annual rainfall of 548 mm and temperatures averaging 23.01 °C, with the soil classified as red sandy loam. During the experimental period, the region received a total rainfall of 49.9 mm, with relative humidity levels recorded at 77.64% in the morning and 28.75% in the afternoon, while the temperature ranged from a maximum of 35.71 °C to a minimum of 18.57 °C. The experiment was designed using a Randomized Complete Block Design (RCBD) with 12 treatments, each replicated three times, utilizing Tomato plants of the Abhilash hybrid variety, spaced 90 x 45 cm apart under irrigated conditions during the spring-summer season.

Experimental details

- **T_1 (100% RDN):** 50% as basal dose + 25% urea at 30 DAT + 25% urea at 45 DAT
- **T_2 (100% RDN):** 50% as basal dose + nano urea (2 ml L^{-1}) at 30 DAT +25% urea at 45 DAT
- **T_3 (100% RDN):** 50% as basal dose + 25% urea at 30 DAT + nano urea (2 ml L^{-1}) at 45 DAT
- **T_4 (100% RDN):** 50% as basal dose + nano urea (2 ml L^{-1}) at 30 and 45 DAT
- **T_5 (75% RDN):** 50% as basal dose + 25% urea at 30 DAT + 25% urea at 45 DAT
- **T_6 (75% RDN):** 50% as basal dose + nano urea (2 ml L^{-1}) at 30 DAT + 25% urea at 45 DAT
- **T_7 (75% RDN):** 50% as basal dose + 25% urea at 30 DAT + nano urea (2 ml L^{-1}) at 45 DAT
- **T_8 (75% RDN):** 50% as basal dose + nano urea (2 ml L^{-1}) at 30 and 45 DAT
- **T_9 (50% RDN):** 50% as basal dose + 25% urea at 30 DAT + 25% urea at 45 DAT
- **T_{10} (50% RDN):** 50% as basal dose + nano urea (2 ml L^{-1}) at 30 DAT + 25% urea at 45 DAT
- **T_{11} (50% RDN):** 50% as basal dose + 25% urea at 30 DAT + nano urea (2 ml L^{-1}) at 45 DAT
- **T_{12} (50% RDN):** 50% as basal dose + nano urea (2 ml L^{-1}) at 30 and 45 DAT
- **RDN:** recommended dose of nitrogen, DAT: Days after transplantation

Fertilizer application

The fertilizer application for tomato cultivation was based on the University of Horticultural Sciences Bagalkot package of practices, which recommends 38 tons of Farm Yard Manure (FYM) and 250:250:250 kg of N:P_2O_5:K_2O per hectare. The fertilizers were applied according to the treatment plan, involving soil application of urea, single super phosphate (SSP), and muriate of potash (MOP), as well as foliar application of nano urea (sourced from the local market). The application schedule consisted of a basal dose administered 2 days after transplanting, comprising half dose of recommended nitrogen along with the full dose of phosphorus and potassium. Subsequent top dressing with urea and nano urea (2 ml L^{-1}) was carried out at 30 and 45 days after transplanting.

Plant sample collection and analysis

Treatment wise plant (leaf and fruit) samples were collected from the field and were brought to laboratory and washed with dilute detergent (0.2%) and hydrochloric acid (0.1%) to remove dust and contaminants, finally washed with distilled water, air dried and oven dried at 65 to 70 °C for 48 hours. Further, dried leaf and fruit sample was powdered separately using stainless steel mixer jar and preserved in air tight plastic cover for further analysis.

The primary nutrient concentration in the plant sample was comprehensively analysed through a series of established methodologies, specifically employing Kjeldahl's digestion and distillation method to quantify the total nitrogen percentage, the vanadomolybdate yellow colour method to determine the total phosphorus percentage, and the flame photometric method to assess the total potassium percentage, all in accordance with the detailed protocols outlined by Piper in 1966.

Results and Discussion

The nutrient content in tomato leaves and fruits was significantly influenced by the type and mode of nitrogenous fertilizer application. Treatments integrating nano urea, especially under 100% recommended dose of nitrogen (RDN), enhanced the uptake and assimilation of primary nutrients nitrogen (N), phosphorus (P) and potassium (K) compared to conventional urea-only treatments (Table 1).

Nitrogen Content in Leaves and Fruits

The highest nitrogen content in both leaves (3.33%) and fruits (0.36%) was recorded under treatment T_4, which received 100% RDN through 50% basal dose and nano urea at both 30 and 45 DAT. This was significantly superior to other treatments. The enhanced nitrogen concentration can be attributed to the improved nitrogen use efficiency (NUE) of nano urea due to its smaller particle size, which enables more effective foliar absorption and sustained nutrient release, as reported by Raliya *et al*. (2016) [1] and Singh *et al*. (2021) [3]. Nano urea likely contributes to higher leaf chlorophyll content and improved enzymatic activity, thereby facilitating greater N uptake and translocation.

Treatments T_2 and T_3, which involved partial substitution of conventional urea with nano urea at either 30 or 45 DAT, also resulted in elevated nitrogen concentrations (3.32% and 3.21% in leaves; 0.35% and 0.33% in fruits), indicating that integrated application of conventional and nano urea is effective in enhancing N availability during critical growth phases.

In contrast, the lowest N content was observed under T_{11} and T_9, both receiving only 50% RDN, confirming that inadequate N supply leads to poor nutrient assimilation. Despite the inclusion of nano urea, these treatments could not match the nutrient content of higher RDN regimes, suggesting that nano urea cannot fully compensate for low total nitrogen inputs, as corroborated by Bhardwaj *et al.* (2022) [6].

Phosphorus Content in Leaves and Fruits

A similar pattern was observed for phosphorus content. Treatment T_4 again recorded the highest P levels in both leaves (0.19%) and fruits (0.34%). This improvement is likely due to the synergistic effect of adequate nitrogen and the nano-scale delivery of urea enhancing root development and rhizosphere activity, thus improving P solubilization and uptake, consistent with the findings of Chhipa (2017) [2].

Treatments with partial nano urea inclusion (T_2, T_3 and T_8) also showed significantly higher P content than urea-only treatments. For instance, T_2 recorded 0.18% P in leaves and 0.33% in fruits, suggesting that foliar nano urea enhances P uptake by sustaining nutrient supply during reproductive growth stages. These observations align with Ramesh *et al.* (2021), who found that nano urea indirectly boosts phosphorus assimilation by stimulating root biomass and microbial activity.

The lowest P levels were found in T_9 (0.11% in leaves, 0.16% in fruits), again highlighting the limitation of nutrient uptake under sub-optimal nitrogen supply. Treatments T_{10} to T_{12}, involving nano urea under 50% RDN, showed moderate improvements, suggesting that nano urea may partially mitigate nutrient deficiencies under low input systems, but is not a substitute for optimal fertilizer.

Potassium Content in Leaves and Fruits

Treatment T_4 once again exhibited the highest potassium content in both leaves (1.73%) and fruits (2.09%), significantly outperforming all other treatments. Enhanced potassium uptake in this treatment may be attributed to the balanced nitrogen nutrition and the systemic effect of nano urea, which likely improves ion uptake efficiency and membrane activity, as described by Adhikari *et al.* (2022) [4].

Other nano-inclusive treatments under 100% and 75% RDN (e.g., T_2, T_3, T_8) also showed elevated K content, supporting the role of nano fertilizers in facilitating macro-nutrient balance. Kumar *et al.* (2021) [5] reported that nano urea improves the root cation exchange capacity, which may lead to improved potassium uptake in tomato.

The lowest potassium values were again seen in treatments with only 50% RDN (T9: 1.05% in leaves; 1.64% in fruits), indicating that insufficient N availability hampers K uptake. This is consistent with the physiological role of nitrogen in enhancing root vigour and K absorption, as previously demonstrated by Khan *et al*. (2020).

The results clearly demonstrate that nano urea, when used in conjunction with or as a partial replacement for conventional urea under 100% RDN, significantly enhances nutrient uptake (N, P, K) in tomato. Among all treatments, T_4 consistently delivered the best performance, suggesting that replacing top-dress urea applications with nano urea sprays at critical stages (30 and 45 DAT) can improve NUE and crop nutritional quality.

The study supports the growing body of evidence that nano-fertilizer strategies can significantly reduce nutrient losses, improve plant nutrient status and contribute to sustainable nutrient management in horticultural crops (Chhipa, 2017; Singh *et al.*, 2021; Adhikari *et al.*, 2022) [2, 5, 4]. However, the data also indicate that nano urea cannot fully substitute for nitrogen under deficit regimes (50% RDN), but may serve as an efficient complementary input.

Table 1: Influence of nitrogenous fertilizers (urea and nano urea) on primary nutrient content in tomato leaves and fruits

Treatments	N (%)		P (%)		K (%)	
	In leaves	In fruits	In leaves	In fruits	In leaves	In fruits
T_1 (100% RDN): 50% as basal dose + 25% urea at 30 DAT + 25% urea at 45 DAT	3.07^{cde}	0.32^{bcd}	0.14^{cdef}	0.27^{bcd}	1.27^{bcd}	1.92^{abc}
T_2 (100% RDN): 50% as basal dose + nano urea (2 ml L^{-1}) at 30 DAT +25% urea at 45 DAT	3.32^{ab}	0.35^{ab}	0.18^{ab}	0.33^{a}	1.51^{ab}	2.06^{ab}
T_3 (100% RDN): 50% as basal dose + 25% urea at 30 DAT + nano urea (2 ml L^{-1}) at 45 DAT	3.21^{abc}	0.33^{abc}	0.17^{abc}	0.31^{ab}	1.40^{abcd}	1.98^{abc}
T_4 (100% RDN): 50% as basal dose + nano urea (2 ml L^{-1}) at 30 and 45 DAT	3.33^{a}	0.36^{a}	0.19^{a}	0.34^{a}	1.73^{a}	2.09^{a}
T_5 (75% RDN): 50% as basal dose + 25% urea at 30 DAT + 25% urea at 45 DAT	2.82^{fg}	0.30^{cdef}	0.13^{def}	0.21^{ef}	1.12^{cd}	1.79^{cd}
T_6 (75% RDN): 50% as basal dose + nano urea (2 ml L^{-1}) at 30 DAT + 25% urea at 45 DAT	3.01^{de}	0.31^{cdef}	0.15^{cd}	0.27^{bcd}	1.14^{cd}	1.81^{bcd}
T_7 (75% RDN): 50% as basal dose + 25% urea at 30 DAT + nano urea (2 ml L^{-1}) at 45 DAT	2.94^{ef}	0.31^{cde}	0.15^{bcde}	0.25^{cde}	1.21^{bcd}	1.81^{bcd}
T_8 (75% RDN): 50% as basal dose + nano urea (2 ml L^{-1}) at 30 and 45 DAT	3.14^{bcd}	0.33^{abc}	0.16^{abcd}	0.29^{ab}	1.46^{abc}	1.93^{abc}
T_9 (50% RDN): 50% as basal dose + 25% urea at 30 DAT + 25% urea at 45 DAT	2.46^{i}	0.27^{f}	0.11^{f}	0.16^{f}	1.05^{d}	1.64^{d}
T_{10} (50% RDN): 50% as basal dose + nano urea (2 ml L^{-1}) at 30 DAT + 25% urea at 45 DAT	2.64^{gh}	0.29^{def}	0.15^{cde}	0.23^{de}	1.09^{d}	1.72^{cd}
T_{11} (50% RDN): 50% as basal dose + 25% urea at 30 DAT + nano urea (2 ml L^{-1}) at 45 DAT	2.44^{hi}	0.29^{def}	0.13^{ef}	0.21^{ef}	1.13^{cd}	1.72^{cd}
T_{12} (50% RDN): 50% as basal dose + nano urea (2 ml L^{-1}) at 30 and 45 DAT	2.71^{g}	0.28^{ef}	0.14^{cdef}	0.23^{de}	1.12^{cd}	1.74^{cd}
S.Em ±	0.06	0.01	0.01	0.02	0.12	0.09
CD (5%)	0.19	0.04	0.04	0.06	0.36	0.27

Conclusion

The present study clearly demonstrates that the strategic integration of nano urea with conventional nitrogen fertilizer significantly enhances the primary nutrient content (N, P, K) in tomato leaves and fruits. Among all treatments, the application of nano urea at both 30 and 45 days after transplanting under 100% recommended nitrogen (T_4) emerged as the most effective strategy, delivering the highest levels of nutrient accumulation. This suggests that nano urea, owing to its enhanced nutrient delivery efficiency, foliar absorption capacity and sustained release, not only improves nutrient uptake but also contributes to improved fruit nutritional quality.

Importantly, while nano urea substantially boosted nutrient availability under full nitrogen regimes, it was less effective under reduced nitrogen levels, indicating that it serves best as a complementary input rather than a complete replacement. These findings highlight the potential of nano-fertilizer as a next-generation approach for sustainable crop nutrition, capable of reducing nitrogen losses, enhancing fertilizer use efficiency and aligning with environmentally responsible agricultural practices.

Future research should explore the long-term effects of nano urea on soil health, plant physiology and yield quality and assess its economic viability and scalability across diverse agro-ecological zones. The integration of such nano-technological innovations could play a pivotal role in shaping a greener, more nutrient-efficient future for agriculture.

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