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Optimizing growth and quality in apple nursery cv. red velox with foliar urea and nano urea application

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ABSTRACT

Nutrient management is crucial in improving the vegetative development and quality of the apple nursery. Foliar feeding with urea and nano urea is thought to be an effective approach for improving nutrient uptake and plant growth. The current study investigated the influence of various urea and nano-urea concentrations on apple nursery cv. Red Velox growth and quality attributes. The treatments were of seven, of which three replications of each treatment were made: T_1: Urea @ 0.3%, T_2: Urea @ 0.4%, T_3: Urea @ 0.5%, T_4: Nano urea @ 0.3%, T_5: Nano urea @ 0.4%, T_6: Nano urea @ 0.5%, and T_7: Control. Foliar sprays were administered once a week in July. Maximum plant height (183.21 cm), stem diameter (15.70 mm), number of branches (3.00) per plant, number of leaves (62.07) per plant, leaf area (33.51 cm^2), leaf chlorophyll content (2.76 mg g^{-1}), leaf N (2.43%) and K (1.63%) content, fresh weight of shoots (246.30 g), dry weight of shoots (116.56 g), number of roots (23.00) per plant, total root length (5.47 m), fresh weight of roots (38.23 g), dry weight of roots (22.13 g), and biomass of plant (138.69 g) were all significantly recorded in nano urea @ 0.4% (T_5). Thus, vegetative growth and quality characteristics of nursery plants of apple showed considerable improvement under nano urea treatment at 0.4% (T_5). A major challenge in the study was the direct comparison between conventional urea and nano urea, as their nutrient release dynamics and foliar absorption efficiencies differ considerably. The study contributes valuable comparative evidence demonstrating that nano urea, when applied at an optimal dose, can outperform conventional urea and serve as a more efficient foliar nitrogen source for apple nursery production.

Keywords: *foliar application; urea; nano urea; Red Velox; shoots; dry weight; growth; quality; fresh weight.*

Introduction

Apple (*Malus × domestica* Borkh.), is a key crop in temperate regions, cultivated all over the world, belonging to the family Rosaceae. It is said to have originated in Central Asia and is widely dispersed over the temperate zones globally. In India, the apple is the primary temperate fruit crop in the North-Western Himalayan area and accounts for an estimated production of 2.87 million tons of apple [7].

Apple orchards utilize either seedling or clonal rootstocks. The quality of nursery plants is crucial for orchard success. To ensure this, we need to focus on efficiently producing authentic planting materials on a larger scale. The use of fertilizers, particularly nitrogen, is fundamental for enhancing plant growth and overall quality. Nitrogen is required for chlorophyll and enzyme production, as well as protein and nucleic acid formation [10].

Urea is commonly used for foliar nitrogen application due to its fast absorption, low harm to plants and ability to enhance nutrient uptake through increased leaf permeability. Foliar nitrogen uptake is efficient in actively growing tissues and can be done whenever leaves are present, especially in spring and fall during nursery production [8]. Nanotechnology offers vast opportunities, especially in agriculture. Nanofertilizers, with dimensions of 1-100 nm, enhance plant growth and nutrition by precisely delivering nutrients. Nanofertilizers boost nutrient efficiency by making nutrients more accessible to plant leaves. They enhance physiological processes, stimulate growth and improve overall plant development. Nanotechnology in fertilizers ensures nitrogen release when crops need it, reducing leaching and emissions while promoting microbial incorporation [12]. Nanofertilizers precisely deliver nutrients to plants, minimizing losses to soil or water. Their high area of surface in relation to volume speeds up the growth of plants and improves nutrient intake via foliage or roots. Nano urea, with 4 per cent nitrogen by weight, is essential for crop growth.

Nitrogen significantly contributes to the vegetative development of nursery plants.

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Foliar application of urea produces greater total leaf area at each given nitrogen fertigation concentration. Foliar application of urea leads to an increase in vegetative growth [22]. The use of nano nitrogen in foliar fertilization significantly impacts shoot diameter, leaf area and leaf nutrient concentrations [5]. Moreover, the adoption of nano nitrogen allows farmers to effectively reduce their urea application by half while still supplying sufficient nitrogen to their crops.

The study seeks to analyze the role of urea and nano urea applied through foliar feeding on vegetative growth of Red Velox plants raised on Bud 9 rootstock in nursery settings, and to evaluate their influence on leaf nutrient (N, P, K) status.

MATERIALS AND METHODS

Department experimental farm is situated in the hilly region of the Western Himalayas, at 30°85'8" North latitude and 77°15'8" East longitude. This area falls under the mid-hill zone (Zone II), which ranges from sub-mountainous to sub-humid conditions, typical of Himachal Pradesh. The climate here is usually mild, with moderately warm summers in May and June. Winters are cold in December and January. The region receives an annual rainfall between 800 and 1500 mm, most of which occurs over the span of July to September.

In 2022–2023, the experiment took place at Pandah Farm, Department of Seed Science and Technology, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan HP. The seven treatments used in the trial were T_1: Urea @ 0.3%, T_2: Urea @ 0.4%, T_3: Urea @ 0.5%, T_4: Nano urea @ 0.3%, T_5: Nano urea @ 0.4%, T_6: Nano urea @ 0.5%, T_7: Control (no treatment). A Randomized Complete Block Design (RCBD) was used to set up the experiment and each treatment had three replications.

During the first week of March, tongue grafting was carried out on Bud 9 rootstock using disease-free, healthy scion wood of Red Velox at a height of 15 cm above ground. Three urea and nano urea foliar sprays were applied weekly during July. The numberof plants in each plot was 20 and the distance between them was 20 cm by 20 cm. The cultural operations like irrigation, weeding etc were carried out in all the treatments. The observations noted for different growth and quality parameters were height of the plant (cm), diameter of the stem (mm), quantity of branches and leaves on each plant, as well as the shoot fresh and dry weight (g) and roots per plant, total length of the roots (m), fresh and dry weight of the roots (g) and biomass of the plant (g).

Statistical analysis

The statistical software OPSTAT was employed to assess data gathered for the investigation. Variance analysis was performed on data values using the Randomized Block Design methodology. The mean values of each character were evaluated at the 5% level of significance utilizing the critical difference.

RESULT

Urea and Nano urea influence on growth parameters

Plant height (cm) and Stem diameter (mm)

Table 1; Fig 2, indicates that the various urea and nano urea treatments showed a significant effect on the plant height and stem diameter of the apple nursery. Treatment T_5 (Nano urea @ 0.4%) produced the highest plant height (183.21 cm) as well as greatest stem diameter (15.70 mm), which was statistically similar to treatment T_4 (Nano urea @ 0.3%) with respect to height and stem diameter, the values reached 181.99 cm and 14.22 mm, respectively, showing a significant advantage over the remaining treatments along with control. Treatment T_7 (Control) produced the lowest plant height (167.22 cm) and stem diameter (11.99 mm).

Number of branches per plant, Number of leaves per plant, and Leaf area (cm^2)

From information provided in Table 1 and Fig 2, Treatment T_5 (Nano urea @ 0.4%) led to greatest branches (3.00) as well as leaves number per plant (62.07) and was statistically comparable to treatment T_4 (Nano urea @ 0.3%) which resulted in 2.33 branches and 62.07 leaves per plant, which was also statistically comparable to treatment T_4 (0.3% Nano urea) resulting in 2.33 mm number of branches per plant, which was acceptable statistically comparable to all treatment contributing to 2.33 mm of branch number per plant over all other treatments including control. Treatment T_7 (control) resulted in the least number of branches (1.22) as well as least quantity of leaves (33.27) on each plant. From both Table 1 and Figure 2, 4, treatment T_5 (Nano urea @ 0.4%) resulted in the greatest leaf area (33.51 cm^2) while treatment T_7 (Control) resulted in the least leaf area (23.01 cm^2).

Fresh weight of shoots (g) and Dry weight of shoots (g)

The results presented in Table 1 along with Fig 3 reveal that shoot weight of fresh and dry apple nursery plants had notably altered by urea and nano urea treatments when compared with all the treatments, including control. Elevated fresh (246.30 g) and dry weight (116.56 g) from shoots was obtained from treatment T_5 (Nano urea @ 0.4%) and had significantly higher fresh and dry weight than all the other treatments, including control. The lowest fresh weight (101.27 g) and dry weight (51.56 g) of apple nursery shoots was the control treatment T_7.

Number of roots per plant, Total root length (m), Fresh weight of roots (g), Dry weight of roots (g) and Biomass of plant (dry weight basis) (g)

The information in Table 1 and Fig 5 makes it abundantly evident that the various urea and nano urea treatments had a substantial impact on the apple nursery overall root length and number of roots per plant. Treatment T_5 (Nano urea @ 0.4%) had the most roots per plant (23.00) and the longest total root length (5.47 m). This was statistically comparable to treatment T_4 (Nano urea @ 0.3%), which had 22.33 roots per plant and a root length of 5.37 m. The smallest number of roots (17.00) and the shortest root length (2.50 mm) were found in Treatment T_7 (Control). Table 1 and Figures 3, 5 show that the different urea and nano urea treatments had a significant effect on the fresh and dry weight (g) of apple nursery shoots. Treatment T_5 (Nano urea @ 0.4%) had the highest fresh (38.23 g) and dried (22.13 g) root weights. In contrast, the control (T_7) had the lowest fresh (14.17 g) and dried (6.80 g) root weights. Based on the data (Table 1 and Figure 5), the biomass of the apple nursery plants was greatly influenced by the different urea and nano urea treatments. Treatment T_5 (Nano urea @ 0.4%) produced the greatest plant biomass (138.69 g), noticeably higher than all treatments, including control. The biomass of the plants under treatment T_7(Control) was the lowest (58.36 g).

PCA Biplot analysis for growth characteristics

The PCA biplot illustrates the variation in plant growth characteristics across the treatments (T_1–T_7). 3.4% of the variation was explained by the second principal component (PC2), which was primarily defined by plant height and dry shoot weight.

The first principal component (PC1) described 95.3% of the variance, largely driven by leaf area, fresh shoot biomass, and stem diameter. T_5 was captured on the positive side of PC1 as it was most closely associated with increased weight of young shoots, area of leaves, and diameter of stem. The treatments were readily distinguished on the two-dimensional axes. Treatments T_4 was associated with increased dry shoot weight, determination was isolated with PC2. Treatment T_7 was identified on the negative side of PC1, indicating comparably weak performance across most of the factors for development. T_1, T_2, T_3 and T_6 treatments tertiarily, indicating intermediate or balanced impacts on the evaluated growth measures, were grouped close to the origin. Overall, the biplot indicates the described traits of shoot biomass had a relatively large influence on treatment differentiation, especially treatment $T_{5,}$ which was the most positively impacted treatment (Fig 4).

90.2% of the overall variation was explained by the first component (PC1), and 7.1% by the second component (PC2). Together, these two components explained 97.3% of the variability in the dataset via the PCA biplot of root system factors. Features of the root system that were a major contributor to treatment differences, dry root weight, fresh root weight, and total plant biomass, were positively correlated with PC1. The total root length exhibited a negative association with PC2, but a good association with PC1. The count of roots represented a contribution along PC2 primarily. T_7 was distinctly separated on the negative side of PC1 which indicates a poor outcome in regards to root development. T_5 and T_4 were located in the positive side of PC1, and they had strong associations with larger amounts of root biomass and root length. While T_6 had a strong association with root length, treatments T_1, T_2, and T_3 clustered modestly in the middle of the biplot, which suggests that they provided rates of root characteristics that were balanced. In summary, the biplot indicated that the main variables of magnitude that caused variation among treatments were root biomass, and root length, with T_5, and T_4 at being the best results (Figure 5).

Urea and Nano urea influence on quality parameters

Leaf chlorophyll content (mg g^{-1}) and Leaf N, P and K content (%)

Table 2 and Fig 6, clearly show the strong influence on various urea and nano urea treatments on leaf chlorophyll content in the apple nursery. Treatment T_5 (Nano urea @ 0.4%) had the highest content of leaf chlorophyll (2.76 mg g^{-1}) which was significantly higher than all other levels of treatment including the control. In treatment T_7 (control), leaf chlorophyll content was reduced to 2.21 mg g^{-1}, the lowest among all treatments. The data (Table 2 and Figure 7, 8) indicate that the leaf N and K content of the apple nursery leaf have been greatly impacted by various urea and nano urea treatments. The application of nano urea at 0.4% (T_5) produced a mean leaf nitrogen content of 2.43%, markedly higher than the 1.97% observed in the control (T_7). The various urea and nano urea treatments did not significantly affect the Leaf P. The means for leaf K were likewise significantly greater with treatment T_5 (Nano urea @ 0.4%) (1.63%) compared to treatment T_7 (Control) (1.38%).

PCA Biplot analysis for qualitative characterstics

The PCA biplot of leaf traits showed that PC1 accounted for 96.8% of the variance, while PC2 contributed 2.1%, together explaining 98.9% of the total variability.

The only traits influencing the separation of treatments were the amount of nitrogen (N), potassium (K), and chlorophyll in the leaves. Of these three, N had the greatest influence along PC1, and K and chlorophyll were also positively correlated on the same axis. In general, T_7 was on the negative side of the PC1 axis, indicating treatment poor performance for these traits but T_5 represented the treatment with the furthest distance along the positive dimension of PC1, showing a strong correlation with higher leaf nutritional contents and chlorophyll concentration. Although T4 and T6 were positioned below the axis and exhibited lower relationships compared to the measured leaf characteristics, T_1, T_2, and T_3 were located closer to the center, indicating moderate or balanced responses. In summary, the analysis demonstrated that the main factor of variation was the accumulation of leaf nutrients, particularly nitrogen, with T_5 representing the treatment with the highest scores (Fig 8).

Discussion

With about 46% nitrogen, urea is a fertilizer rich in nitrogen. Farmers widely use it to boost crop yield and promote plant growth. Despite its widespread use, conventional urea has a relatively low nitrogen use efficiency, which results from major nutrient losses through processes like leaching, volatilization, and denitrification. To overcome these drawbacks, nano urea has been introduced through the application of nanotechnology. It consists of nitrogen in nano-sized particles, which allows for better absorption through plant leaves and reduces nutrient wastage. This modern approach presents a more effective, eco-friendly, and sustainable option compared to traditional urea fertilizers.

Plant height and stem diameter may have increased because of using nano urea topically , which helps efficient nitrogen absorption along with translocation to various plant parts [21]; [23]. Its small size enables easy penetration through stomatal openings and effective distribution throughout the plants [9]. Sufficient supply of nitrogen probably increased auxin biosynthesis and the activity of enzymes, which encouraged cell elongation along with enlargement, ultimately leading to taller plants [19];[13] and nitrogen is essential for making proteins and nucleic acids, as well as for protoplasm production, promotes cell division and activate meristematic activity, leading to the formation of additional tissues and organs. The plants that had the highest amount of branch number per plant were probably the ones receiving a spray applied to the leaves with nano urea. By having a consistent supply of nitrogen in a few critical periods of growth, they were able to produce more lateral branches [18];[15]. The rise in the leaf count per plant could be attributed to the sufficient nitrogen supply that boosted protoplasmic components and stimulated cell lengthening and division processes [18];[3]. Nitrogen mainly helps with cell division, growth, and tissue development. Consequently, this enhances plant development by producing more and bigger leaves (greater leaf area).

Chlorophyll serves as the key pigment that drives the process of photosynthesis. It mainly influences how well a plant can carry out photosynthesis and, in turn, its growth [21]. The effective absorption of nitrogen through nano urea likely enhanced chlorophyll synthesis, contributing to improved photosynthesis [13]. Due to its microscopic particle size and higher surface area, nano urea leads to better nutrient uptake and use efficiency, as the smaller particles have more contact opportunities with the plant, enhancing nutrient absorption [6].

The increase in shoot fresh weight may have resulted from increased photosynthetic activity and more photosynthates because of a greater number, a greater area of leaves and better growth [23];[13]. The gain in shoot dry weight from nano urea foliar application likely improved the physiological activity of the plant leaves by boosting chlorophyll. The increased chlorophyll content improved the rate of photosynthesis, leading to greater glucose accumulation and, as a result, higher weight of the plants, both fresh and dried [13]. Enlarged root number along with longer roots, can likely be attributed to the enhanced vegetative growth resulting from the proper application of nano urea, which promoted greater production and the transport of assimilates into the root system. The augmentation in fresh weight of roots could be associated with enhanced translocation of photoassimilates to the roots, driven by the improved vegetative growth. This probably led to more roots that developed more effectively [23]; [1]. The dry root weight can be attributed to the efficient absorption of nano urea, which enhanced vegetative growth parameters. This likely led to higher production, assimilation and translocation of photoassimilates to the root system, contributing to the observed increase in dry weight [1]. The increase in the biomass of plants (dry weight basis) was likely due to improved growth and a higher number of branches, resulting in greater photosynthesis and producing more photosynthates [24]; [2].

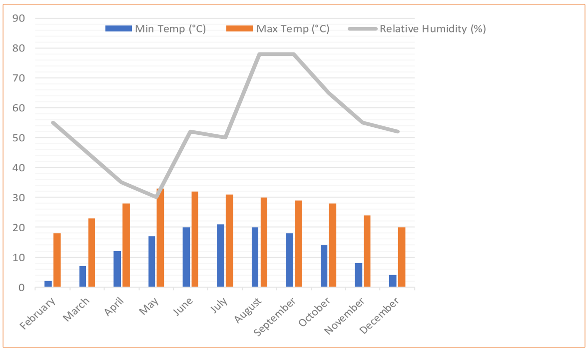

Fig 1. Mean temperature and Relative humidity data of experimental site

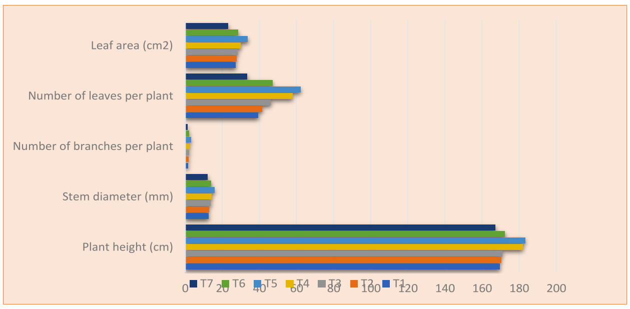

Fig 2. Response of apple nursery plants cv. Red Velox to foliar application of urea and nano urea on vegetative parameters

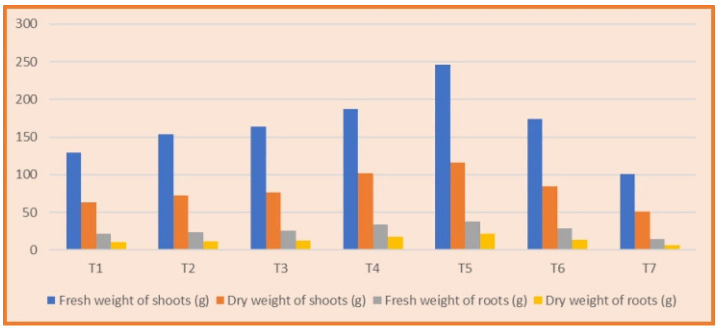

Fig 3. Impact of foliar application of urea and nano urea on Fresh weight of shoots, dry weight of shoots, Fresh weight of roots, dry weight of roots in apple nursery plants cv. Red Velox

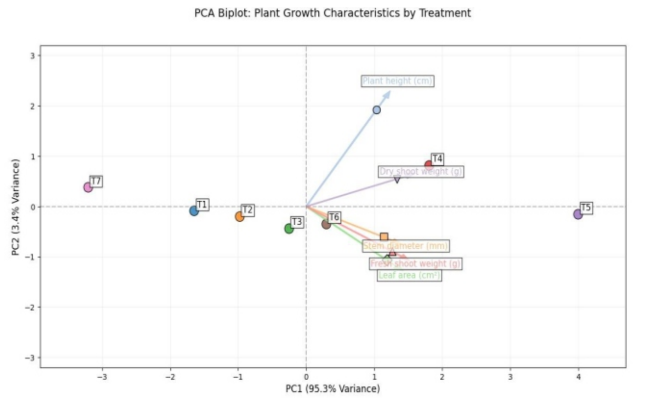

Fig 4. PCA Biplot analysis for plant height, stem diameter, fresh shoot weight, dry shoot weight and leaf area of apple nursery cv. Red Velox

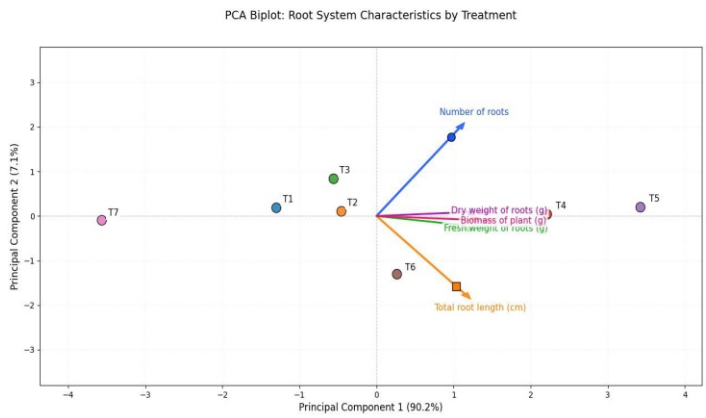

Fig 5. PCA Biplot analysis for different root parameters and biomass of plant of apple nursery cv. Red Velox

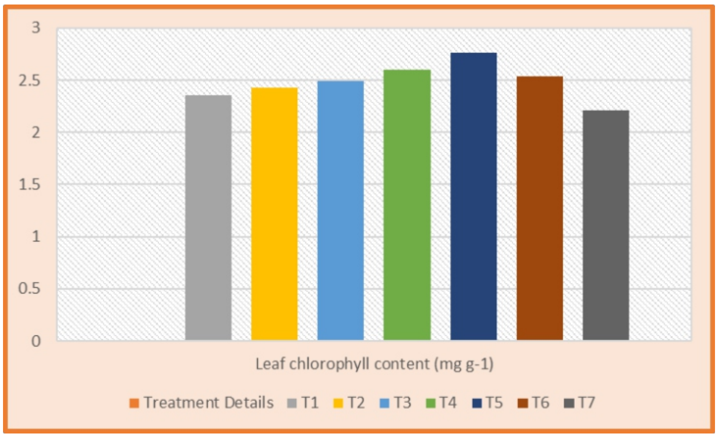

Fig 6. Effect of foliar nutrition with urea and nano urea on leaf chlorophyll content of apple nursery cv. Red Velox

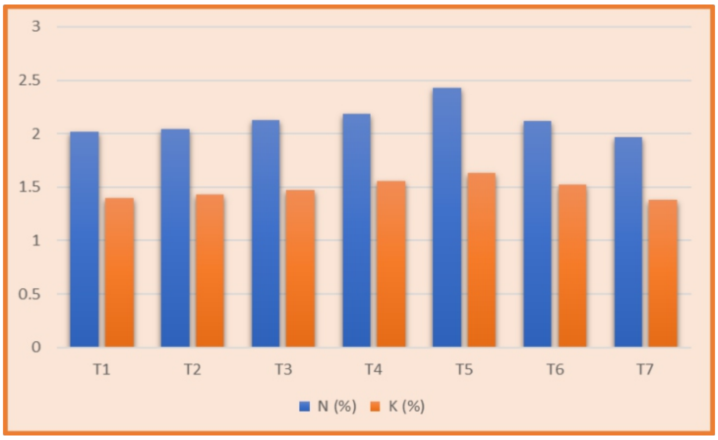

Fig 7. Effect of foliar sprays of urea and nano urea on N (%) and K (%) content of apple nursery cv. Red Velox

Table 1. Influence of foliar urea and nano urea application on growth performance of apple nursery cv. Red Velox

Treatments Details	Plant height (cm)	Stem diameter (mm)	Number of branches per plant	Number of leaves per plant	Leaf area (cm^2)	Fresh weight of shoots (g)	Dry weight of shoots (g)	Number of roots	Total root length (m)	Fresh weight of roots (g)	Dry weight of roots (g)	Biomass of plant (dry weight basis) (g)
T_1	169.55	12.55	1.55	39.27	27.10	129.13	62.96	20.00	3.87	21.35	10.29	73.25
T_2	170.22	12.77	1.78	41.47	27.50	153.82	72.43	20.67	4.36	24.10	11.58	84.01
T_3	170.99	13.66	2.00	45.93	28.31	164.31	76.23	21.00	3.37	25.43	12.22	88.45
T_4	181.99	14.22	2.33	57.73	29.80	187.07	101.90	22.33	5.37	34.34	17.76	119.66
T_5	183.21	15.70	3.00	62.07	33.51	246.30	116.56	23.00	5.47	38.23	22.13	138.69
T_6	172.33	13.99	2.11	47.00	28.49	174.50	84.66	18.67	5.29	28.99	13.68	98.34
T_7	167.22	11.99	1.22	33.27	23.01	101.27	51.56	17.00	2.50	14.17	6.80	58.36
Mean	**173.60**	**13.55**	**2.00**	**46.68**	**28.24**	**165.20**	**80.90**	**20.38**	**4.31**	**26.65**	**13.50**	**94.40**
$CD_{0.05}$	**2.21**	**1.58**	**0.70**	**1.23**	**1.91**	**5.94**	**4.97**	**0.90**	**0.12**	**3.48**	**2.24**	**5.65**

Table 2. Impact of foliar sprays of urea and nano urea on quality traits of apple nursery cv. Red Velox

Treatment Details	Leaf chlorophyll content (mg g^{-1})	Leaf N, P and K (%)		
		N	P	K
T_1	2.36	2.02	0.23	1.40
T_2	2.43	2.04	0.22	1.43
T_3	2.49	2.13	0.21	1.47
T_4	2.60	2.19	0.23	1.56
T_5	2.76	2.43	0.21	1.63
T_6	2.54	2.12	0.20	1.52
T_7	2.21	1.97	0.19	1.38
Mean	**2.48**	**2.13**	**0.21**	**1.48**
$CD_{0.05}$	**0.06**	**0.12**	**NS**	**0.05**

Conclusion

The investigation offers the clear role of nano urea in enhancing physiology, development as well as overall quality of cv. Red Velox apple nursery plants. The extremely effective treatment used was 4 ml L^{-1} of nano urea sprayed on leaves once weekly for three consecutive weeks in July. In terms of multiple growth and quality traits, this treatment produced the best results compared to all others. The improvements in plant height, stem diameter, number of branches, leaf production, and leaf area all suggest that the plants receiving this nano urea spray treatment achieved maximum vegetative growth. Increased absorption and accumulation of nitrogen and potassium in the foliage provided a demonstration that nano urea not only supplied nutrients in a more effective way, but also improved the capacity of plants, in terms of growth and physiology, to take up and use them. Therefore, the findings endorse the use of nano urea in apple nursery management as a productive, environmentally friendly, and resource-efficient alternative to conventional urea.

Future scope of the study

Future studies may assess whether nano urea–treated nursery plants maintain their growth advantages after field transplanting. Standardizing optimal nano urea concentrations across cultivars and environments, along with investigating its physiological mechanisms, will further strengthen its application. Evaluating its environmental impact, economic feasibility, and integration with other nutrient strategies can also help establish nano urea as a sustainable option for apple nursery production.

Conflict of interests

The authors declare that there is no competing interest.

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Author's contribution

R.D. (Rewa Dhiman) conducted the experiment and analyzed the data; C.L.S. (CL Sharma) conceptualized the research and guided throughout the experiment; R.S., P.V. and S.K. helped in main manuscript writing and forming tables; Tanvi Rana helped in data curation.

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