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Efficacy of Nano-urea in Flowering and Fruiting of Litchi Cultivars Grown under the sub-Himalayan Terai Region of West Bengal

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Abstract

A scientific investigation was carried out in 2021 during January to June at Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India, to evaluate the flowering and fruiting behavior of litchi (*Litchi chinensis* Sonn.), a subtropical fruit species indigenous to South China and Southeast Asia. The crop holds substantial economic significance in India, with West Bengal recognized as one of the major litchi-producing states. The application of nanostructured urea fertilizer, referred to as "Nano-urea," has been demonstrated to enhance crop yields while mitigating the environmental pollution associated with conventional fertilization practices. So, this study was conducted to evaluate the effects of treated and non-treated nano-urea fertilizers on various growth and quality parameters in litchi cultivars. The experiment comprised 14 treatments, with a primary focus on fruiting parameters and several fruit quality attributes. The results indicated significant variations among treatments, with T_{12} showing the highest total number of flowers (637.10), the highest percentage of fruit set (2.25), and notable fruit quality metrics, including a fruit weight of 12.18 g and TSS of 15.70°Brix. Conversely, T_3 recorded lower metrics, particularly for fruit weight (14.50 g) and TSS (13.55°Brix). Overall, treatments involving nano-urea resulted in improved fruit attributes compared with the non-treated controls. These data suggest that the application of nano-urea positively influences flower and fruit development, thereby enhancing the overall quality of litchi cultivars. These findings highlight the potential of urea as a viable option for optimizing litchi production and quality.

Keywords: Litchi, nano-urea, fruit quality, and fertilizer treatment

1. Introduction

Litchi (*Litchi chinensis* S.) is one of the important fruits in subtropical or tropical regions. Litchi is in high demand due to its attractive red colour and availability throughout the summer season in Northern India, where it is predominantly grown. Litchi, accessible in December and January, is becoming increasingly popular in southern India. In 2020, the total litchi production in China reached 2.55 mt, and the high-yield variety "Feizixiao" output accounted for 80.3% of the total litchi production (Yin et al., 2024). Litchi provides high levels of phenolics and ascorbic acid. Litchi is a commercially significant fruit crop, esteemed for its distinctive aesthetic qualities, including a vivid red pericarp, and its desirable sensory attributes, such as a sweet, succulent aril. Furthermore, its high concentration of bioactive compounds contributes to its economic importance. Litchi is an excellent source of various nutritional components, including polysaccharides, vitamins, and minerals, as well as a wide spectrum of polyphenols, notably flavonoids, steroids, terpenes, phenols, and flavan-3-ol molecules (Castillo-Olvera et al., 2025; Kumar et al., 2020; Qu et al., 2021). These diverse compounds confer established functional and nutraceutical properties to the fruit. A panicle is a fruiting body that produces hundreds of female and two types of male flowers. A single bunch can generate up to 800 female flowers and 10–20 fruits, resulting in a good yield. However, the majority of the fruit does not make it to harvest. There are numerous concerns about a fall in litchi output. Litchi has a high rate of fruit drop, which is a problem. Litchi trees undergo significant fruit drop between fruit set and maturity, with just a small proportion of fruits reaching maturity in many cultivars (Lal et al., 2025). So Farmers tend to pursue high yields and economic benefits for litchi production by applying large amounts of chemical fertilizers. However, the overuse of chemical fertilizers results in a decline in soil quality and progressive reduction in productivity (Huanget al., 2017; Calleja et al., 2015). Moreover, excessive fertilizer application can have adverse environmental effects, leading to poor fertilizer utilization, increasing non-point source pollution, N_2O, and CO_2 emissions, potentiating global warming (Abubakar et al., 2022) and affecting sustainable crop or fruit production (Liang et al., 2022).

Nano-fertilizers are significant in agriculture because they boost crop development, increase nutrient efficiency, and lower fertilizer loss and cultivation costs (Ghosal et al., 2024). They are extremely useful for precise nutrient administration, increasing agricultural growth stages, and providing nutrients while crops are growing. Nanotechnology provides immense promise for sustainable agriculture, particularly in underdeveloped countries. Liquid nano-urea is more than 80% efficient at supplying nitrogen to plants, whereas regular urea is just 30% to 50% effective. Nano urea liquid particles are 30 nanometers in size and have 10,000 times the surface area to volume ratio of typical granular urea. These tiny particles absorb nutrients more efficiently from plants, resulting in less environmental loss and consumption. Slow-release fertilizers are considered environmentally friendly fertilizers that have good nutrient-controlled release effects in farmlands or orchards and can provide a steady and long-acting nutrient supply to the soil (Ni et al., 2010). Previous studies have shown that PUR-coated nitrogen urea and controlled-release nitrogen can decrease nitrate-nitrogen leaching and improve vegetable or fruit yield and quality (Dong Feng et al., 2019; Geng et al., 2021; Moe et al., 2019; Sun et al., 2020). The application of coated urea can also reduce the number of chemical fertilizers applied and improve their utilization efficiency (Li et al., 2021). The focus of current research is the maintenance of orchard soil quality, reduction of chemical fertilizer costs, and improvement of fruit yield and quality. Slow-release fertilizers have received increasing attention as highly utilizable and environmentally friendly.

2. Materials and Methods

The experiment was conducted during 2021 in January to June at the Instructional Farm, Department of Pomology & Post Harvest Technology, Faculty of Horticulture, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India. The University is located at 26°19’86” N latitude and 89º23’5” E longitude, under the sub-Himalayan Terai agro-climatic zone of West Bengal at 43 m above sea level to judge the flowering and fruiting characteristics of litchi cultivars by treating with nano-urea fertilizer application.

2.1. Total number of flowers panicle^{-1}

To determine the average-sized panicles were tagged in order to collect data on the total number of flowers in each. Each opened bloom was identified as a male, hermaphrodite, functional male, or functional female and counted before being removed from the panicle with forceps on a daily basis.

2.2. Percent fruit set

The total number of blooms in each treatment was recorded, and the procedure was repeated three times. The initial fruit set was utilized to calculate the fruit set percentage.

2.3. Fruits panicle^{-1}

The number of fruits panicle^{-1} were recorded for each replicate of all treatments.

2.4. Days taken to harvest of fruits

The date of harvesting in all treatments was recorded when fruits developed a bright red color along with flattened tubercles.

2.5. Fruit weight

Weight of ten fruits from each of the three replicates were recorded by weighing the samples on an electric balance. The average weight of a fruit was calculated for each treatment and expressed in grams (g).

2.6. Fruit length and diameter

The length and diameter of ten fruits were also recorded (cm) simultaneously for each replicate of all treatments.

2.7. Juice content

Juice content was recorded by extracting the juice in a standard and specified manner and then relating the juice volume to the original mass of the fruit.

2.8. Total soluble solid (TSS) contents

The total soluble solid content of freshly harvested litchi fruits was recorded using a hand refractometer and was expressed as a percentage. The observations were recorded in replication-wise and expressed in treatments.

2.9. Total sugars

Total sugars were determined according to the method described by Lane and Eyon. With the use of a mortar and pestle, 10 g of newly harvested fruit sample was crushed with lukewarm water. A 100 ml volumetric flask was used, and the volume was raised to 100 ml. Then 20 ml of juice was placed in a volumetric flask, along with 1–2 ml of concentrated HCL. A drop of phenolphthalein indicator was put to it the next day. Then 1N NaOH solution is added till it turns into pink colour. In the burette, a sample was taken. Then, in a 100 ml conical flask, add 2 ml Fehling’s solution A and 2 ml Fehling’s solution B to make a volume of 50 ml, and then add 1–2 drops of methylene blue indicator. Continuous heating of the flask and drop-by-drop pouring of the sample from the burette were used for titration. Finally, the end point was determined by appearance of a brick red colour

2.10. Reducing sugar

Lane and Eyon» method were used for the estimation of reducing sugar. 10 g of freshly collected fruit sample was taken it was crushed with luke warm water with the help of mortar and pestle. 100 ml of volumetric flask was taken and volume 30 made up to 100 ml. sample was taken in burette. Then 100 ml of conical flask was taken. Added 2 ml of Fehling's solution A and 2 ml of Fehling's solution B and volume made up to 50 ml. then added 1–2 drop of methylene blue indicator into it. Brick red colour given the endpoint was determined by titration of the sample against Fehling's solution

2.11. Titrable acidity

The total acid content of litchi fruits was calculated (replication and treatment wise) by titrating the pulp extract with NaOH (Ranganna, 1986). using 1% phenolphthalein as the indicator. Since the predominating acid of ripe litchi fruit is "malic acid" (80% of all the acids), the calculation of total acidity was based on the equivalent weight of malic acid.

2.12. Ascorbic acid content

The ascorbic acid content of litchi fruits was calculated by titrating the pulp extract the 2, 6- dichlorophenol indophenol visual titration method (Ranganna, 1986). This was expressed in terms of milligrams of ascorbic acid 100 g^{-1} of pulp.

2.13. Statistical analysis

Significant differences between treatments were assessed using one-way analysis of variance (ANOVA; $p<0.05$). Duncan's multiple range tests were performed for multiple comparisons using the, R Software Statistics program version 4.3.2.1.

3. Results and Discussion

3.1. Total number of flowers panicle^{-1}

The total number of flowers panicle^{-1} showed significant variation (Table 1). The data ranged from 407.90 to 637.10. The maximum number of flowers panicle^{-1} was produced by the cultivar Shahi treated (T_{12}) (593.87) while the minimum number of flowers panicle^{-1} was produced by Bombai control (T_7) (407.90). According to Singh et al. (2012), flowers are produced in late winter or early spring, and three types of flowers open in succession on the same panicle. Low flowering of litchi was also reported by previous many workers. The management of litchi orchards includes watering, fertilizer application, girdling, growth regulators, and pruning, which greatly influence tree growth, yield, and profitability; however, the physiology of growth, flowering, and cropping needs to be described as the lack of flowering is not only due to the weather or the timing of shoot growth, but it is also related to shoot maturity, physiology, biochemical, nutritional, and hormonal status of shoot buds during flower initiation/and vegetative phase, which is a critical period of the production cycle.Litchi trees experience significant flower and fruit drop between flowering and fruit maturity (Singh, 2015, Malhotra, 2016, Srivastava et al., 2014). Only a limited percentage of flowers (2–18%) reach maturity in various cultivars (Lal, 2018). The amount of blossom and fruit drop varies with species, season, and tree age. Fruit drop is caused by failure of pollination and fertilization, embryo abortion, nutrition, hormonal imbalance, and environmental causes such as high temperature, low humidity, and strong westerly winds. (Lal et al., 2025).

3.2. Percent fruit set

The data on the percentage of fruit set (Table 1) revealed that the maximum percentage of fruit set (4.78) was observed in Bombai-treated plants (T_8), whereas the Muzaffarpur control (T_{13}) recorded the minimum percentage of fruit set (3.52%). The data obtained from table 1 were not significant among all treatments.

3.3. Fruits panicle^{-1}

The data on fruits panicle^{-1} in table 1 were not significantly different among the cultivars selected for the study. The maximum number of fruits panicle^{-1} (23.20) was observed in the Shahi treatment (T_{12}), while the minimum number of fruits panicle^{-1} (17.70) was recorded in the Bedana control (T_5).

3.4. Days taken to harvest of fruits

The data presented in table 1 for the days taken to harvest fruits ranging from 103.59 to 126.23 days. The maximum number of days taken to harvest (126.23) was observed in the Bedana control (T_5), and the minimum number of days taken to harvest (103.59) was observed in the Bombai control (T_7).

3.5. Fruit weight, length and diameter

The data in Table 1 revealed that the maximum fruit weight (20.60 g) was recorded in the Bedana-treated plants (T_6), while the minimum fruit weight (10.47 g) was recorded in the Chinese control (T_9). However, the data obtained from table 3.1 exhibited significant variation among all treatments. The maximum fruit length (3.26 cm) was observed in the China treatment (T_{10}), and the minimum fruit length (2.32 cm) was recorded in the Elaichi treatment (T_4). The data on fruit length in table 1 showed significant variation among all treatments. The maximum fruit diameter (2.85 cm) was recorded in the Bedana control (T_5) whereas Elaichi control (T_3) recorded the minimum fruit diameter (2.15 cm). However, the data showed non-significant variation in fruit diameter among all treatments. The smaller particle size of urea allows for better penetration into plant tissues, facilitating more effective nutrient uptake than conventional fertilizer. Similarly, results also obtained by Dalal et al. (2011) who reported that foliar application of 2% urea at flowering, peanut size of fruits and at second growth phase significantly increased the fruit yield (71.35 kg tree^{-1}) over control (52.19 kg tree^{-1}). The increase in yield attributes and yield of acid lime was recorded with foliar application of nitrogen through urea may be helped to increase the fruit set either by improving pollen germination or by helping the growth of pollen tubes and thus facilitate in timely fertilization before the stigma loses its receptivity was reported by Yaseen et al. (2010).

In a study carried out by Chang and Lin (2006), who found that when the litchi cultivar Yu Her Pauwas sprayed with gibberellic acid at 5 and 10 mg l 14 days^{-1} after full bloom in order to increase the fruit weight of shriveled seeds, it

Table 1: Effect of treated and non-treated nano urea fertilizer application on the fruiting and quality parameters of litchi cultivars

Treatment	Total numbers of flowers panicle^{-1}	Percent fruit set	Fruits panicle^{-1}	Days taken to harvest of fruits	Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)
T_1	469.08^{fg}	2.13^{abc} (4.08)	19.60^{a}	110.32^{efgh}	18.40^{abc}	3.03^{abc}	2.54^{abc}
T_2	488.63^{ef}	2.15^{abc} (4.14)	21.30^{a}	104.19^{gh}	20.37^{ab}	3.09^{abc}	2.36^{bc}
T_3	430.57^{gh}	2.09^{abc} (3.92)	18.60^{a}	109.87^{efgh}	14.50^{d}	2.63^{def}	2.15^{c}
T_4	465.57^{fg}	2.13^{abc} (4.03)	21.63^{a}	111.80^{defg}	18.77^{abc}	2.32^{f}	2.47^{abc}
T_5	505.00^{def}	2.13^{abc} (4.05)	17.70^{a}	126.23^{a}	17.19^{c}	2.38^{ef}	2.85^{a}
T_6	531.20^{cde}	2.14^{abc} (4.12)	19.67^{a}	120.26^{abc}	20.60^{a}	2.74^{cde}	2.68^{ab}
T_7	407.90^{h}	2.23^{ab} (4.54)	19.00^{a}	103.59^{h}	14.65^{d}	2.91^{abcd}	2.46^{abc}
T_8	439.70^{gh}	2.29^{a} (4.78)	22.63^{a}	103.73^{h}	18.21^{bc}	3.13^{abc}	2.52^{abc}
T_9	540.00^{cd}	2.09^{abc} (3.87)	19.17^{a}	109.07^{efgh}	10.47^{f}	2.85^{bcd}	2.37^{bc}
T_{10}	571.70^{bc}	2.15^{abc} (4.14)	22.09^{a}	106.43^{fgh}	11.30^{ef}	3.26^{a}	2.69^{ab}
T_{11}	614.13^{ab}	2.14^{abc} (4.14)	22.45^{a}	118.30^{bcd}	10.71^{f}	3.04^{abc}	2.51^{abc}
T_{12}	637.10^{a}	2.25^{ab} (4.62)	23.20^{a}	114.15^{cdef}	12.18^{ef}	3.21^{ab}	2.79^{ab}
T_{13}	575.47^{bc}	2.00^{c} (3.52)	19.10^{a}	124.23^{ab}	12.52^{def}	2.80^{cd}	2.22^{c}
T_{14}	591.83^{ab}	2.05^{bc} (3.71)	20.30^{a}	115.23^{cde}	13.03^{de}	3.11^{abc}	2.67^{ab}
SEm±	15.77	0.07	2.33	2.68	0.79	0.13	0.15
SEd	22.30	0.109	3.29	3.79	1.12	0.19	0.21
CD (p=0.05)	45.85	NS	NS	7.83	2.31	0.38	NS

Table 1: Continue...

Treatment	Juice content (ml)	Seed (g)	TSS (° Brix)	Total sugar(%)	Reducing sugar (%)	Acidity (%)	Ascorbic acid (mg 100 g^{-1})
T_1	7.53^{ab}	3.77^{ab}	14.77^{cdef}	11.09^{ef}	10.63^{defg}	0.41^{b}	23.40^{cde}
T_2	7.93^{a}	3.80^{a}	14.67^{def}	11.34^{def}	11.20^{bcde}	0.33^{cde}	24.04^{c}
T_3	6.53^{c}	2.87^{cde}	13.55^{g}	10.29^{g}	10.70^{defg}	0.41^{b}	27.65^{b}
T_4	7.17^{abc}	2.47^{de}	14.14^{fg}	11.43^{bcde}	10.71^{defg}	0.39^{bcd}	27.91^{b}
T_5	7.53^{ab}	2.15^{ef}	15.70^{ab}	11.89^{abcd}	11.52^{abcd}	0.50^{a}	29.43^{a}
T_6	7.73^{ab}	1.62^{f}	15.84^{a}	12.10^{ab}	12.17^{a}	0.43^{b}	30.19^{a}
T_7	3.77^{f}	3.86^{a}	15.27^{abcde}	11.92^{abcd}	11.65^{abc}	0.39^{bc}	20.46^{fg}
T_8	4.50^{def}	3.32^{abc}	15.63^{abc}	12.11^{ab}	11.94^{ab}	0.31^{e}	20.70^{f}
T_9	4.17^{ef}	3.47^{abc}	14.40^{efg}	10.72^{fg}	10.44^{efg}	0.52^{a}	22.38^{e}
T_{10}	4.50^{def}	3.15^{abcd}	14.87^{bcdef}	11.40^{cdef}	10.82^{cdef}	0.41^{b}	22.66^{de}
T_{11}	6.97^{bc}	2.98^{bcd}	15.53^{abcd}	12.03^{abc}	10.79^{cdef}	0.32^{de}	19.28^{g}
T_{12}	7.57^{ab}	2.37^{def}	15.70^{ab}	12.13^{a}	11.39^{abcd}	0.33^{cde}	20.13^{fg}
T_{13}	4.63^{de}	2.70^{cde}	14.57^{ef}	11.37^{cdef}	9.81^{g}	0.38^{bcd}	23.38^{cde}
T_{14}	5.07^{d}	2.36^{def}	14.83^{bcdef}	11.99^{abcd}	10.27^{fg}	0.37^{bcde}	23.86^{cd}
SEm±	0.27	0.27	0.31	0.23	0.32	0.02	0.41
SEd	0.38	0.39	0.44	0.33	0.45	0.03	0.58
CD (p=0.05)	0.79	0.80	0.91	0.68	0.94	0.06	1.2

T_1: Calcuttia control; T_2: Calcuttia treated; T_3: Elaichi control; T_4: Elaichi treated; T_5: Bedana control; T_6: Bedana treated; T_7: Bombai control; T_8: Bombai treated; T_9: China control; T_{10}: China treated; T_{11}: Shahi control; T_{12}: Shahi treated; T_{13}: Muzaffarpur control; T_{14}: Muzaffarpur treated was concluded that both concentrations of GA_3 significantly increased the fruit length, fruit weight, aril, and pericarp weight as compared to the control. Jat and Kacha (2014); Etehadnejad and Aboutalebi (2014) has reported that the improvement in growth and development of acid lime with foliar application of nitrogen nutrient might be due to the fact that urea and nano-urea plays an important role in growth and development of plants as nitrogen is an important component of protoplasm which helps in chlorophyll synthesis resulting in an increase in photosynthetic activities and thus resulting in accumulation of more carbohydrates leading to flower initiation and profuse flowering. Similar findings were also reported by Parmar et al. (2014) who reported an adequate and balanced supply of nutrients and a reduction in nutrient loss, which are indispensable for growth and development.

3.6. Juice content

The data in table 1 showed significant variation with respect to the juice content among all the treatments studied. The data ranged from 3.77 to 7.93 ml. The maximum juice content (7.93 ml) was observed in Calcuttia-treated (T_2), and the minimum juice content (3.77 ml) was recorded in the Bombai control (T_7).

3.7. Seed by weight

Significant variation is shown in table 1 with respect to seed weight, which ranged from 1.62 to 3.86 g. The maximum weight of seeds (3.86 g) was recorded in the Bombai control (T_7), whereas the minimum weight of seeds (1.62 g) was recorded in the Bedana-treated (T_6). However, increases in yield and number of fruit tree^{-1} with N fertilization have been previously reported in citrus by He et al. (2022); Zhao et al. (2025). Mitre et al. (2012); Hasani et al. (2016) and Davarpanah et al. (2017) reported that the increase in fruit size is in line with data found in previous studies on pomegranate and other crops.

3.8. Total soluble solid (TSS) contents

The data presented in table1 showed significant variation with respect to TSS content. The data ranged from 13.55 to 15.84°Brix. The highest TSS content (15.84°Brix) was recorded in Bedana-treated (T_6), whereas the lowest TSS content (13.93°Brix) was recorded in Elaichicontriol (T_3). This might be due to the fact that nitrogen helps to increase the TSS content by converting complex substances into simple substances, which enhances the metabolic activity in fruits. These findings are consistent with those of results as supported by Parmar et al. (2014) and Ennab (2016). Similar results were also achieved by Sravani et al. (2025), who revealed that an increase in TSS after N application can be attributed to the important roles of N in chloroplast structure, CO_2 assimilation, and activation of enzymes involved in photosynthesis, which lead to an increase in photosynthesis, carbohydrate accumulation, and also consequently increase in total soluble solids. These findings are in good agreement with and are well supported by Mishra et al. (2012); (Jat and Kacha, 2014); Parmar et al. (2014); El-Sayed et al. (2016); and Gurjar et al. (2018).

3.9. Total sugar and reducing sugar

The perusal of data on total sugar, as presented in Table 1, revealed that the maximum total sugar content (12.13%) was recorded in Shahi treated (T_{12}), whereas the minimum total sugar content (10.29%) was recorded in China (T_5). However, the data obtained in table 1 showed significant variation. Significant variation was observed, as presented in table 1, with respect to reducing sugars among the treatments under study. The maximum reducing sugar content (12.17%) was recorded in the Bedana-treated plants (T_6), while the Muzaffarpur control (T_{13}) had the lowest reducing sugar content (9.18%). It might be due to the fact that nitrogen helps to increase the reducing sugar, non-reducing sugar and total sugars by its action of converting complex substances into simple ones, which enhances the metabolic activity in fruits. Nitrogen fertilization leads to an increase in reducing, non-reducing, and total sugars in pomegranates by Abdel-Sattar et al. (2023). Similarly, Sharma et al. (2014) reported that the effect of N fertilizers on sugar increase might help in the absorption of other mineral nutrients to improve fruit quality.

3.10. Titrable acidity

The data presented in table 1 indicated significant variation with respect to titratable acidity. The maximum titratable acidity (0.52) was recorded in the Chinese control (T_9) followed by Bedana control (T_5) (0.50), while the minimum titratable acidity content (0.31%) was recorded in Bombai-treated (T_8). The decrease in titratable acidity with nitrogen sprays might be due to an increase in the synthesis and translocation of organic acids in the fruits. This may be due to the effect of nitrogen, which increases sucrose transport in fruits, resulting in low acidity and high-quality fruits. According to Li et al. (2021) it was suggested that the increase in nitrogen levels is conducive to the delivery of sorbitol and sucrose from the extracellular space into the cells.

3.11. Ascorbic acid content

The data on ascorbic acid content in table 1 revealed significant variation and the maximum ascorbic acid content (30.19 mg 100 g^{-1}) was recorded in Bedana (T_3) and followed by Bedana control (T_5) (29.43 mg 100 g^{-1}) the minimum ascorbic acid content (19.28 mg 100 g^{-1}) was recorded in Shahi control (T_{11}). There was a comparable drop in acidity with the progression of fruit ripening. These results support the view that acids can be used as respiration substrates when sugars have been consumed, or that acids can participate in the synthesis of phenolic compounds, lipids, and volatile aromas, as well as provide a series of metabolites that are used in a variety of processes that reflect the dominance of sweet flavors in fruits.

4. Conclusion

These data indicate that the integration of urea into litchi farming presents a viable solution for enhancing crop productivity and quality while promoting sustainable agricultural practices. Although the initial results are encouraging, further research is needed to fully understand the long-term effects and optimize the application methods. As farmers face increasing demands for higher yields and better quality produce, nano-urea may serve as a crucial tool in modern agriculture to balance productivity with environmental stewardship.

5. References

Abdel-Sattar, M., Al-Obeed, R.S., Aboukarima, A.M., Górnik, K., Eshra, D.H., 2023. Improvement of the physico-chemical properties, nutritional, and antioxidant compounds of pomegranate fruit cv.'Wonderful'using integrated fertilization. Horticulturae 9(2), 195.

Abubakar, S.A., Hamani, A.K.M., Chen, J., Sun, W., Wang, G., Gao, Y., Duan, A., 2022. Optimizing N-fertigation scheduling maintains yield and mitigates global warming potential of winter wheat field in North China Plain. Journal of Cleaner Production 357, 131906. https://doi.org/10.1016/j.jclepro.2022.131906.

Calleja-Cervantes, M.E., Fernández-González, A.J., Irigoyen, I., Fernández-López, M., Aparicio-Tejo, P.M., Menéndez, S., 2015. Thirteen years of continued application of composted organic wastes in a vineyard modify soil quality characteristics. Soil Biology & Biochemistry 90, 241–254. https://doi.org/10.1016/j.soilbio.2015.07.002.

Castillo-Olvera, G., Sandoval-Cortes, J., Ascacio-Valdes, J.A., Wong-Paz, J.E., Álvarez-Pérez, O.B., FloresLópez, M.L., Aguilar, C.N., 2025. Litchi chinensis: nutritional, functional, and nutraceutical properties. Food Production, Processing and Nutrition 7(1), 3. https://doi.org/10.1186/s43014-024-00275-z.

Chang, J.C., Lin, T.S., 2006. GA_3 increases fruit weight in 'Yu Her Pau'litchi. ScientiaHorticulturae 108(4), 442–443.

Davarpanah, S., Tehranifar, A., Davarynejad, G., Aran, M., Abadía, J., Khorassani, R., 2017. Effects of foliar nano-nitrogen and urea fertilizers on the physical and chemical properties of pomegranate (*Punica granatum* cv. Ardestani) fruits. HortScience 52(2), 288–294.

Dalal, R.P.S., Navjot, A.T., Brar, J.S., 2011. Effect of foliar application of nutrients on leaf mineral composition and yield of Ber (*Ziziphus mauritiana* Lamk.) under arid conditions. Annals of Arid Zone 50(1), 53–56.

Dong Feng, G., Ma, Y., Zhang, M., you Jia, P., hong Hu, L., Guo Liu, C., Hong Zhou, Y., 2019. Polyurethane-coated urea using fully vegetable oil-based polyols: Design, nutrient release and degradation. Progress in Organic Coatings 133, 267–275. https://doi.org/10.1016/j.porgcoat.2019.04.053.

El-Otmani, M., Ait-Oubahou, A., Taibi, F.Z., Lovatt, C.J., 2002. Efficacy of foliar urea as an N source in sustainable citrus production systems. ActaHorticulturae 594, 711–617.

El-Sayed, F.S., El-Aenen, M.A., Helal, M.M., 2016. Effect of foliar applications of urea on flowering, fruit set, yield and fruit quality of Washington Navel orange trees. Egyptian Journal of Horticulture 43(2), 299–316.

Ennab, H., 2016. Effect of organic manures, bio-fertilizers and npk on vegetative growth, yield, fruit quality and soil fertility of Eureka lemon trees (*Citrus limon* (L.) Burm). Journal of Soil Sciences and Agricultural Engineering 7(10), 767–774.

Etehadnejad, F., Aboutalebi, A., 2014. Evaluating the effects of foliar application of nitrogen and zinc on yield increasing and quality improvement of apple cv. golabkohanz. Indian Journal of Fundamental and Applied Life Sciences 4(2), 2231–6345. https://www.cibtech.org/J-LIFE-SCIENCES/PUBLICATIONS/2014/Vol-4-No-2/JLS-020-026-ABOUTALEBI-EVALUATION-KOHANZ.pdf.

Geng, Y., Wang, J., Sun, Z., Ji, C., Huang, M., Zhang, Y., Xu, P., Li, S., Pawlett, M., Zou, J., 2021. Soil N-oxide emissions decrease from intensive greenhouse vegetable fields by substituting synthetic N fertilizer with organic and bio-organic fertilizers. Geoderma 383, 114730.

Ghosal, S., Rathour, T.P., Datta, P., Sarkar, N.S., Lal, D., Gurjar, J., Reja, R.M., Paul, M., Chawla, R., 2024. Influence of nano urea on the fruit qualitative features of litchi cv. Bombai grown in new alluvial zone of West Bengal India. Plant Archives 24, 149–153. https://doi.org/10.51470/plantarchives.2024.v24.SP-GABELS.022.

Gurjar, M.K., Kaushik, R.A., Rathore, R.S., Sarolia, D.K., 2018. Growth, yield and fruit quality of Kinnow mandarin as affected through foliar application of zinc and boron. Indian Journal of Horticulture 75(1), 141–144.

Hasani, M., Zamani, Z., Savaghebi, G., Sofla, H.S., 2016. Effect of foliar and soil application of urea on leaf nutrients concentrations, yield and fruit quality of pomegranate. Journal of Plant Nutrition 39(6), 749–755.

He, Y., Li, W., Zhu, P., Wang, M., Qiu, J., Sun, H., Zhang, R., Liu, P., Ling, L., Fu, X., Chun, C., 2022. Comparison between the vegetative and fruit characteristics of' Orah (*Citrus reticulata* Blanco) mandarin under different climatic conditions. Scientia Horticulturae 300, 111064.

Huang, J., Xu, C.C., Ridoutt, B.G., Wang, X.C., Ren, P.A., 2017. Nitrogen and phosphorus losses and eutrophication potential associated with fertilizer application to crop land in China. Journal of Cleaner Production 159, 171–179.

Jat, G., Kacha, H.L., 2014. Response of guava to foliar application of urea and zinc on fruit set, yield and quality. Journal of Agrisearch 1(2), 86–91.

Kumar, N., Neeraj, Pratibha, Singla, M., 2020. Enhancement of storage life and quality maintenance of litchi (*Litchi chinensis* Sonn.) fruit using chitosan:pullulan blend antimicrobial edible coating. International Journal of Fruit Science 20(3), 1662–1680. https://doi.org/10.1080/15538362.2020.1828224.

Lal, N., Kumar, A., Pongener, A., Pandey, S.D., 2025. Major litchi production problems in India. Applied Fruit Science 67(1), 1–10. https://doi.org/10.1007/s10341-025-01271-4.

Li, G.H., Cheng, G.G., Lu, W.P., Lu, D.L., 2021. Differences of yield and nitrogen use efficiency under different applications of slow release fertilizer in spring maize. Journal of Integrative Agriculture 20(2), 554–564.

Liang, Z., Jin, X., Zhai, P., Zhao, Y., Cai, J., Li, S., Yang, S., Li, C., Li, C., 2022. Combination of organic fertilizer and slow-release fertilizer increases pineapple yields, agronomic efficiency and reduces greenhouse gas emissions under reduced fertilization conditions in tropical areas. Journal of Cleaner Production 343, 131054. https://doi.org/10.1016/J.JCLEPRO.2022.131054.

Malhotra, S.K., 2016. Water soluble fertilizers in horticultural crops-An appraisal. Indian Journal of Agricultural Sciences 86(10), 1245–56.

Mishra, S., Choudhary, M.R., Yadav, B.L., Singh, S.P., 2011. Studies on the response of integrated nutrient management on growth and yield of ber. Indian Journal of Horticulture 68(3), 318–321.

Moe, K., Moh, S.M., Htwe, A.Z., Kajihara, Y., Yamakawa, T., 2019. Effects of integrated organic and inorganic fertilizers on yield and growth parameters of rice varieties. Rice Science 26(5), 309–318. https://doi.org/10.1016/j.rsci.2019.08.005.

Ni, B., Liu, M., Lu, S., Xie, L., Wang, Y., 2010. Multifunctional slow-release organic– inorganic compound fertilizer. Journal of Agricultural and Food Chemistry 58(23), 12373–12378. https://doi.org/10.1021/jf1029306.

Parmar, J.M., Karetha, K.M., Rathod, P.J., 2014. Effect of foliar spray of urea and zinc on growth and flowering attributes of guava (*Psidium guajava*) cv. Bhavnagar Red. Bhavnagar red. Advance Research Journal of Crop Improvement 5(2), 140–143.

Qu, S., Li, M., Wang, G., Zhu, S., 2021. Application of ABA and GA_3 alleviated browning of litchi (*Litchi chinensis* Sonn.) via different strategies. Postharvest Biology and Technology, 181, 111672. https://doi.org/10.1016/J.POSTH ARVBIO.2021.111672.

Singh, S.K., 2015. Shoot physiology in relation to flowering and fruiting in litchi. ResearchProject Format–I (Flagship Project 2), PME Cell, National Research Centre on Litchi, Muzaffarpur, India.

Singh, B., Singh, S., Sandhu, S., 2012. Effect of growth retardants on vegetative growth, flowering and fruiting of litchi cv. Calcuttia. Horticulture Flora Research Spectrum 1, 29–33.

Sravani, V., Rajeswari, R., Gopalakrishnan, M., Senthil Kumar, M., Kavitha, M., Bharathi, C., 2025. Nanonutrient formulations–impact on growth and post-harvest quality of fruits and vegetables. Communications in Soil Science and Plant Analysis 56(5), 811–823.

Srivastava, A.K., Das, S.N., Malhotra, S.K., Majumdar, K., 2014. SSNM-based rationale of fertilizer use in perennial crops: A review. Indian Journal of Agricultural Sciences 84(1), 3–17.

Sun, H., Zhou, S., Zhang, J., Zhang, X., Wang, C., 2020. Effects of controlled-release fertilizer on rice grain yield, nitrogen use efficiency, and greenhouse gas emissions in a paddy field with straw incorporation. Field Crops Research 253, 107814. https://doi.org/10.1016/j.fcr.2020.107814.

Yaseen, M., Ahmad, M., 2010. Nutrition management in citrus: effect of multinutrients foliar feeding on the yield of kinnow at different locations. Pakistan Journal of Botany 42(3), 1863–1870.

Yin, J., Li, Y., Liu, H., Duan, Y., Jiao, Y., Zhu, Z., Luo, J., Xie, C., Zhang, H., Zhang, X., Li, D., 2024. Using slow-release fertilizers ensures the maintenance of litchi (*Litchi chinensis* Sonn.) production by enhancing soil nutrient supply and optimizing microbial communities. Applied Soil Ecology 195, 105265.

Zhao, Y., Xiong, H., Luo, Y., Hu, B., Wang, J., Tang, X., Wang, Y., Shi, X., Zhang, Y., Rennenberg, H., 2025. Long-term nitrogen fertilization alters the partitioning of amino acids between citrus leaves and fruits. Frontiers in Plant Science 15, 1516000.

