Impact of foliar application of Urea and Nano urea levels on quality, physiological and leaf nutrient content attributes of Acid lime (*Citrus aurantifolia* Swingle) cv. Kagzi in Vertisols of Jhalawar district in Rajasthan

ABSTRACT

This study attempted the efficacy of various Urea and Nano urea treatments on Kagzi lime fruit characteristics, such as weight, length, breadth of juice recovery, total soluble solids (TSS), acidity, TSS/Acidity ratio ascorbic acid content, and pH value of juices. There were some significant differences in the reaction of Kagzi lime to these treatments. The Urea treatment at 2% (T4) always gave the top values for the fruit weight, length, breadth; juice recovery, TSS content, TSS/Acidity ratio; ascorbic acid content, and juice pH. While the Nano urea treatments showed positive effects, Urea treatment at 2% had the overall better performance. This implies that Urea at this level was superior in improving the fruit quality factors, which may be used to optimize Kagzi lime cultivation methods. In particular, the variables such as fruit characteristics, juice properties and nutritional content, chlorophyll content; relative water contents in leaves of leaf nutrient contents were positively influenced by 2.0% treatment Urea application These protocols led to significant improvements in fruit weight, length, and width being greater as good juice contented and TSS which increased considerably the levels of Ascorbic acid were improved, chlorophyll content enhanced while there were reduced effects despite that resulted from this prophylactic treatment. Moreover, it resulted in the maximum level of leaf nitrogen and phosphorous. These results show that Urea has significant influences on the quality of acid lime cv. The highest favorable results were noticed in the 2.0% Urea treatment administered by Kagzi lime.

Keywords: - Citrus, Acid Lime, Kagzi, Quality, Urea, Nano urea, Leaf N, P, K

1. INTRODUCTION

Acid lime, scientifically referred to as *Citrus aurantifolia* Swingle., is an evergreen fruit tree belonging to the Rutaceae family. It is characterized by its small size and bears fruits known as acid limes. This fruit is well known for its distinctive tangy flavour and is highly valued for its versatile applications in both culinary and medicinal uses. The acid lime tree is native to Southeast Asia, particularly India, and is commonly cultivated in tropical and subtropical regions around the world. Globally, India holds first rank in the production of acid lime (*Citrus aurantifolia* Swingle), with a production of 35.86 lakh metric tons and an area of 3.06 lakh hectares, as per the third advance estimate of the Ministry of Agriculture and Farmers Welfare data for the years 2021–22 (Anon., 2021-22). Acid lime is gaining popularity among citrus growers due to its versatility in adapting to diverse agro-climatic and soil conditions, cost-effective cultivation, year-round fruit-bearing capability, improved fruit storage properties, and steady demand in the domestic market (Ladaniya *et al.* 2020). The increasing interest in foliar fertilizers is driven by the numerous advantages of foliar application methods. These include the rapid and efficient response to plant needs, reduced product quantities required, and independence from soil conditions. The application of supplementary foliar fertilization during crop growth has been acknowledged for its ability to enhance the mineral status of plants and ultimately boost crop yield (Kolota and Osinska 2001). Most plants absorb foliar-applied urea rapidly and hydrolyse the urea in the cytosol (Witte *et al.*, 2002).

Urea and Nano urea can be applied to plants through the foliage, enabling efficient nitrogen management, that reduces nitrogen losses to the environment. (Yildrim *et al*. 2007). Acid lime crop is economically important for farmers as it provides year-round harvest, ensuring a steady return. With the growing concern for sustainable agriculture and environmental protection, there was a need felt to explore alternate nutrient management practices. Traditional urea application may lead to nutrient losses through leaching and volatilization. Evaluating the efficacy of Nano urea in comparison can provide insight into its potential to enhance nutrient use efficiency, thereby conserving nutrient resources. By comparing the effect of Urea and Nano urea on acid lime, foliar treatment results in better productivity and improved fruit quality. The agricultural significance of optimizing nutrient management strategies in tropical regions, particularly Latin America, has garnered substantial attention due to its implications for soil quality and productivity. Acid lime (*Citrus aurantifolia* Swingle.) cultivation, a key component of tropical agriculture (Rodriguez et al., 2015), requires meticulous attention to enhance fruit quality (Olivares and Franco, 2015) and overall productivity (Hernandez et al., 2018a). This study focuses on the impact of foliar application of urea and nano urea levels on Kagzi lime, providing insights into the physiological and nutritional aspects of the crop.

2. MATERIALS AND METHODS:

The investigation titled "Comparative assessment of Urea and Nano Urea foliar applications on quality, physiological, and leaf nutrient content attributes of Acid lime (*Citrus aurantifolia* Swingle) cv. Kagzi, was carried out from June to December 2022 at the well-established Kagzi lime orchard of the College of Horticulture and Forestry, Jhalawar, a constituent College of Agriculture University, Kota. The study involved 14-year-old acid lime plants, totalling fifty-four in number, spaced at regular intervals of 6 m x 6 m. The experiment included nine treatments, incorporating different concentrations of urea (0.5%, 1.0%, 1.5%, and 2.0%) and nanourea (500 ppm, 1000 ppm, 1500 ppm, and 2000 ppm). Two rounds of foliar spraying were administered for each treatment, commencing on July 7, 2022, followed by the second spray 30 days later. The soil composition predominantly had a clay-loam texture with traces of heavy clay. The primary objective of this study was to assess the influence of urea and nano urea foliar applications on the quality attributes of Kagzi acid lime, yielding significant insights for the improvement of agricultural practices:

1. "Quality parameters were recorded at horticultural maturity of fruits during the second fortnight of December 2022".
2. "Leaf nutrient analysis and physiological parameters were initially measured and then again after the experiment as per standard analytical procedures".

Keeping all these facts in mind, the present investigations were conducted to provide valuable information to farmers and the agriculture industry to optimize their nutrient management practices.

2.1 TREATMENT DETAILS

The area of the experimental block was 2160 m^2 accommodating 54 acid lime cv. Kagzi plants. Treatment comprises two factors, first four levels of Urea and second, four levels of Nano Urea and control. Thus a total of nine treatments having a unit replication of two plants with a total of 54 plants were tested applying these treatments. The details of treatments evaluated under study are given in Table 1.

Table 1. Details of various treatments including Urea and Nano Urea

T_0 :(water spray),

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T_1 :(Urea @ 0.5%),
T_2 :(Urea @ 1.0%),
T_3 :(Urea @ 1.5 %),
T_4 :(Urea @ 2 %),
T_5 :(Nano urea @ 500 ppm),
T_6 :(Nano urea @1000 ppm),
T_7 :(Nano urea @ 1500ppm)
T_8 :(Nano urea 2000ppm) as applied foliar treatments.

Leaf chlorophyll content was quantified following the method suggested by Sadasivam and Manickam (1997). Leaf N content was determined using the alkaline potassium permanganate method (Thakur *et al*. 2012). The leaf P and K content in leaf samples was assessed using the methodology outlined by Thakur *et al*. (2012).

The data collected during the experiment was subjected to statistical analysis using the Analysis of variance (ANOVA) technique. The significance of the treatment was tested through F-test at a 5% level of significance. To evaluate the significance of the differences, the critical difference (CD) was calculated among the different treatments.

3. RESULTS AND DISCUSSION:

Below are the comprehensive results of the experiment, supported by relevant tables:

3.1 Fruit Weight: Significant variations were observed in the fruit weight of Kagzi lime in response to various Urea and Nano urea treatments. Table 2 presents the results, revealing that the maximum fruit weight (67.90 g) was recorded in cv. Kagzi lime with the T_4 treatment (Urea @ 2%), while the minimum fruit weight (40.89 g) was recorded in the T_0 treatment. Although there was an increase in the fruit weight of acid lime with Nano urea, the T_8 treatment with Nano urea application @ 2000 ppm showed a value of 52.68 g. Despite this, the overall highest fruit weight was recorded with the T_4 treatment. The increase in fruit weight observed with the T_4 treatment (Urea @ 2%) can be attributed to the enhanced nitrogen availability provided by urea, which is a vital nutrient required for protein, enzyme, and chlorophyll synthesis involved in various biochemical processes within the plant. The foliar application of urea through the T_4 treatment likely stimulated the photosynthetic rate, leading to higher carbohydrate production and ultimately resulting in increased fruit weight.

3.2 Fruit length (mm): Various urea and Nano urea treatments led to significant variations in the fruit length of acid lime. The findings presented in Table 2 demonstrate that the highest fruit length (52.72 mm) in acid lime cv. Kagzi was observed in the T_4 treatment (Urea @ 2%), while the lowest fruit length (41.76 mm) was recorded in the T_0 treatment. Similarly, the application of different levels of Nano urea also increased the fruit length in acid lime cv. Kagzi, with the maximum fruit length (45.70 mm) recorded in the T_8 treatment using Nano urea @ 2000 ppm. The overall results indicate that the fruit length was highest in the T_4 treatment (Urea @ 2%) compared to the Nano urea treatments. The role of nitrogen in enhancing cell wall strength and flexibility might have influenced fruit shape and breadth. Additionally, nitrogen is closely associates with the absorption and assimilation of other essential nutrients like potassium (K) and calcium (Ca), crucial for cell expansion and fruit development. The increase in fruit length can be attributed to enhanced water uptake and turgor pressure within the fruit, facilitating the expansion and elongation of fruit tissues. the results of this study are in agreement with previous findings reported by various researchers in different fruit crops. Debaje *et al*. (2011) observed similar trends in acid lime, while Jat and Laxmidas (2014) reported comparable results in guava.

3.3 Fruit breadth (mm): The findings presented in Table 2 indicate that the highest fruit breadth in acid lime cv. Kagzi (47.36 mm) was observed in the T_4 treatment (Urea @ 2%), while the minimum length (40.87 mm) was recorded in the T_0 (Control) treatment. The application of different levels of Nano urea resulted in an increase in fruit length, with the maximum value (46.35 mm) measured in the T_8 treatment (Nano urea@ 2000ppm). However, the overall maximum enhancement in fruit length (47.36 mm) was recorded in the T_4 treatment (Urea @ 2%) when compared to the Nano urea treatments. Nitrogen's role in cell wall strengthening and increasing its flexibility may have contributed to the shaping and broadening of that fruit. Additionally, nitrogen is intimately associated with the uptake and accumulation of vital nutrients like potassium (K) and calcium Ca; which are required for cell elongation as well as fruit development. Elongation in fruit tissues of acid lime and the consequent increase in length can be due to enhanced water uptake that causes elevated pressure within fruits, which then leads to expansion and elongation. Likewise, Prasad *et al*. (2015) and Al-Obeed *et al*. (2017) found analogous outcomes in Kinnow mandarin.

3.4 Juice (%): The results presented in table 2 demonstrate that the maximum juice recovery in Kagzi lime (51.19%) was achieved in response to the T_4 treatment (Urea @ 2%), while the minimum (38.34%) was observed in the T_0 (Control) treatment. Additionally, the application of Nano urea treatments resulted in an increase in juice recovery percentage, and the highest juice recovery (49.21%) was obtained through the T_8 treatment (Nano urea @ 2000 ppm). Overall, upon comparative evaluation of Urea and Nano urea treatments, it was found that the highest juice recovery (51.19%) was estimated in the T_4 treatment, which included Urea @ 2.0%. These findings are further supported by Rathore and Chandra (2003), Prasad et al. (2015), and Sawale et al. (2021) in Sai Sharbati. Moreover, El-Tanany et al. (2009), Debaje et al. (2011), Prasad et al. (2015), Al-Obeed *et al*. (2017), and Yadav *et al*. (2020) also reported consistent results in their studies on acid lime and Kinnow mandarin. The higher juice recovery obtained in the T_4 treatment can be attributed to several factors. Firstly, the application of T_4 might have stimulated increased carbohydrate production, leading to an enhancement in cell number and size in various fruit tissues, including the juice sac in acid lime. Additionally, urea, present in the T_4 treatment, plays a role as a source of nitrogen. It increases the osmotic pressure within the fruit cells, causing water to move from the surrounding tissue into the fruit cells, thereby increasing the juice percentage. The present findings are consistent with the results reported by Lakshmipathi *et al*. (2015), Prasad *et al*. (2015), Rokaya *et al*. (2019) in Kinnow mandarin, Yadav *et al*. (2020) in acid lime, and Senjam and Singh (2021) in Assam lemon. The convergence of these results reinforces the understanding of the impact of the T_4 treatment on juice recovery and supports the effectiveness of urea as a nutrient in enhancing juice yield in acid lime

3.5 TSS (^{0}brix): The data presented in table 2 illustrates the variations in the total soluble solids (TSS) content of acid lime cv. Kagzi under different Urea and Nano urea treatments. The highest TSS value (10.46$_0$brix) was recorded in the T_4 treatment, where Urea was applied at a rate of 2%. The application of Nano urea at different doses resulted in inconsistent variations in TSS levels, with the highest values (10.28^{o}brix) observed in both the T^5 treatment (Nano urea @ 500 ppm) and the T_7 treatment (Nano urea @ 1500 ppm), which were higher than the control group (9.30^{0}brix). However, upon overall evaluation, the maximum TSS content (10.46^{o}brix) was measured in the T_4 treatment with Urea at 2.0%. The increase in TSS observed under various treatments can be attributed to the influence of Urea and Nano urea on metabolic pathways, resulting in the accumulation of sugar in the fruit juice and an increase in enzymatic activity, contributing to higher TSS levels.

3.6 Acidity (%): After reviewing the results of the data in Table 2, it is apparent that the acidity of the lime samples from different foliar treatments showed remarkable differences in the lime juice. The greatest acidity was measured from T2 treatment (urea at 5%) with 14.63%, while the lowest acidity of 6.47% was recorded in T4 treatment (Urea at 2%), indicating a significantly lower value compared to the other treatments. On the other hand, the treatment with the highest acidity content was at 7.25% that was marked as T0, which acted as the control. Additionally, the different doses of Nano urea treatments showed lower content of acidity on all Nano urea treatments. The lowest content of acidity (6.53%) was obtained in the T8 treatment involving Nano urea application at the rate of 2000 ppm as a treatment during the stage of horticultural maturity of acid lime fruits. There is a number of physiological factors that have been found to influence the acidity of the acid lime fruits, which include organic acid synthesis, respiration rates, sugar content and nitrogen availability, which can affect the acidity levels. This is evidenced by the work of Chouhan et al. (2018), Yadav et al. (2020) in acid lime, Abdallah (2020) in Minneola Tangelo, and Senjam and Singh (2021) in Assam lemon, which confirm present results and emphasize factors. The high TSS: higher acid ratio of T4 treatment can be attributed to the improved sugar concentration in the acid lime fruits.

3.7 TSS/Acidity ratio: The TSS/Acidity ratio is a crucial parameter used to assess fruit quality in acid lime and other citrus fruits, indicating the balance between sweetness and acidity, which are essential aspects of fruit taste. The T_4 treatment, with Urea applied at 2%, resulted in the highest TSS/acidity ratio (1.65), indicating a better balance between sweetness and acidity in the fruit and favourable fruit quality. In contrast, the T_0 treatment (control) exhibited the lowest TSS/acidity ratio (1.27), suggesting an imbalanced combination of sweetness and acidity in the fruit. Nano-urea treatments showed varying trends in the TSS/acidity ratio at different doses, implying inconsistent effects on fruit quality. Among the nano-urea treatments, the T_8 treatment with nano-urea applied at 2000 ppm recorded the highest TSS/acidity ratio (1.56), indicating a relatively better balance of sweetness and acidity compared to other nano-urea treatments. Overall, the comparative evaluation of Urea and Nano-urea treatments revealed that the best TSS/acidity ratio (1.65) was obtained in the T_4 treatment, where urea was applied at 2.0%. This suggests that the urea treatment at this concentration was more effective in achieving the desired fruit quality with the right balance of sweetness and acidity. The convergence of these results reinforces the understanding of the impact of the T_4 treatment on juice recovery and supports the effectiveness of Urea as a nutrient in enhancing juice yield in acid lime. These findings align with the results reported by Prasad *et al.* (2015), Chouhan *et al*. (2018) in acid lime, Yadav *et al.* (2020) in acid lime, and Senjam and Singh (2021) in Assam lemon. With an increased supply of nitrogen, the acid lime plant might produce and accumulate more sugars, leading to higher TSS levels in the fruit juice. These findings are in line with the results reported by Saleem *et al*. (2008) in sweet orange. The research also indicates that the availability of nitrogen contributes to a rise in N_2 content within the acid lime cv. Kagzi fruits. This increase can be attributed to the higher availability of ammonia, which enhances the presence of glutathione. Glutathione indirectly leads to an increase in the levels of ascorbic acid and has the ability to regenerate ascorbic acid from its oxidized form (dehydroascorbic acid), thereby maintaining an active pool of ascorbic acid within the fruit tissue. These results are further supported by previous research by Carpenter *et al*. (2018) and Chouhan *et al*. (2018) conducted on acid lime under the Malwa plateau region, as well as the findings of Rokaya *et al*. (2019). The consistency of these supporting studies strengthens the validity and relevance of the present investigations. The observed variations in Kagzi lime responses to urea and nano-urea treatments underscore the scientific relevance of this study. Notably, urea at a concentration of 2% consistently outperformed Nano urea across a spectrum of fruit attributes, including weight, dimensions, juice recovery, total soluble solids (TSS), acidity, TSS/acidity ratio, ascorbic acid content, and juice pH. These findings contribute to the broader discourse on nutrient management in tropical fruit agriculture (Campos, 2023), emphasizing the superiority of urea at specific concentrations (Araya-Alman *et al*., 2020; Olivares et al., 2022a).

3.8 Ascorbic acid (mg/100 ml of juice): The level of ascorbic acid in acid lime fruits displayed significant variation when exposed to different treatments involving urea and Nano urea. Among these treatments, the highest concentration of ascorbic acid, measuring 61.89 mg/100 mL, was observed in the T_4 treatment, which involved the application of urea at a concentration of 2%. On the other hand, the control group (T_0 treatment) exhibited the lowest ascorbic acid content, measuring 44.56 mg/100 mL The ascorbic acid content increased with varying doses of Nano urea, and the maximum ascorbic acid content (57.75 mg/100 ml) was achieved in the T_8 treatment (Nano urea @ 2000 ppm). However, the overall comparative assessment revealed that the highest ascorbic acid content (61.89 mg/100 ml) was recorded in the T_4 treatment, where urea was applied at a concentration of 2.0%. In the context of tropical agricultural areas in Latin America, where soil quality and productivity are pivotal concerns, the current research aligns with the need for tailored nutrient application strategies (Olivares et al., 2022b; Calero *et al.*, 2022). Comparative analyses with existing studies in similar agro-ecological contexts reveal the applicability of the findings to broader agricultural practices (López *et al.*, 2019; Lobo et al., 2023; Rey et al., 2022). The demonstrated efficacy of 2% urea treatment in positively influencing fruit characteristics, juice properties, and leaf nutrient contents resonates with the challenges faced in tropical agricultural fruit areas in Latin America (Olivares, 2016; Hernandez et al., 2018b; Hernandez and Olivares, 2020).

3.9 Juice pH: The current research on foliar applications of Urea and Nano urea treatments in acid lime cv. Kagzi fruits revealed variations in juice pH The highest juice pH value (2.40) was observed in T_4 treatment, which showed similar performance to T_3 and T_2 treatments with pH values of 2.38 and 2.35, respectively. On the other hand, the lowest juice pH (2.22) was recorded in the control group, T_0. Moreover, the application of Nano urea treatments at different levels resulted in lower juice pH values (ranging from 2.22 to 2.28) compared to various Urea levels. The higher juice pH could be attributed to the fact that urea application might influence the uptake and utilization of other essential nutrients such as potassium (K^+) and calcium (Ca^{2+}) which play a role in maintaining the pH balance in plant cells. The results of present findings are in accordance with those reported by Lasa *et al*. (2012).

The observed variations in Kagzi lime responses to Urea and Nano urea treatments underscore the scientific relevance of this study. Notably, Urea at a concentration of 2% consistently outperformed Nano urea across a spectrum of fruit attributes, including weight, dimensions, juice recovery, total soluble solids (TSS), acidity, TSS/acidity ratio, ascorbic acid content, and juice pH. These findings contribute to the broader discourse on nutrient management in tropical fruit agriculture (Campos, 2023), emphasizing the superiority of Urea at specific concentrations (Araya-Alman et al. 2020; Olivares et al. 2022a).

Physiological Attributes

3.9 Chlorophyll content (mg g^{-1})

The application of foliar treatments comprising Urea and Nano urea on acid lime cv. Kagzi led to a noticeable increase in total chlorophyll content across various treatments. The changes in chlorophyll accumulation of Kagzi lime leaves in response to foliar application of Urea and Nano Urea treatments are depicted in Fig.1.The T_4 treatment, which involved Urea at a 2% concentration, exhibited the highest chlorophyll a, chlorophyll b, and total chlorophyll content, with values of 1.217 mg g^{-1}, 0.717 mg g^{-1}, and 1.933 mg g^{-1}, respectively. Conversely, the lowest accumulation of chlorophyll a (1.140 mg g^{-1}), chlorophyll b (0.463 mg g^{-1}), and total chlorophyll (1.603 mg g^{-1}) was observed in the T_0 (control) treatment, which did not receive

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any foliar treatment. The significant increase in chlorophyll a, chlorophyll b, and total chlorophyll content in the T_4 treatment can be attributed to the positive response of acid lime plants to the foliar application of Urea at a concentration of 2.0%. This response likely led to enhanced chlorophyll synthesis and improved photosynthetic efficiency in the plants. Additionally, the increased activities of Rubisco (Ribulose-1,5-biphosphate carboxylase/oxygenase), a key enzyme involved in carbon fixation during photosynthesis, may have contributed to the heightened chlorophyll content. These findings align with the work of Dhaliwal and Rohela (2016) in rough lemon and Abdallah (2020) in their studies, further validating the positive impacts of foliar Urea treatments on chlorophyll content in citrus plants. The present results highlight the potential of Urea foliar application as an effective method to enhance photosynthetic activity and overall health in acid lime cv. Kagzi.

3.10 Relative water content (%)

The pictorial presentation of data in fig.2 depicts the RWC (Relative water content) levels of acid lime cv. The highest relative water content (RWC% = 75.86%) during the period December 2022 was recorded in T4 treatment (Urea @ 2.0%) and the lower value of RWC% (68.05%) was determined in T0 (Control) treatment. The RWC in the T4 treatment was relatively better than that of the other three treatments, the reason being several aspects. As a first problem, it may be possible that osmotic adjustment will increase, resulting in a greater osmotic potential of the leaf cell. That keeps the cells with high water content and a comparably high RWC (%). Secondly, Urea may act to alter stomatal behaviour, which would result in improved stomatal regulation and higher leaf water retention. Moreover, nitrogen promotes cell elongation, cells can therefore hold more water, thus higher RWC (%). These results further showcase the correlation with Mohammadi and Khejri (2018) in date palm and, hence, reconfirm the Urea treatment's positive effect on acid lime plants' relative water content. The results of the study allow for drawing valuable conclusions that are relevant to the improvement of the cultivation methods of the Kagzi limes, particularly in regions with the Vertisols, such as the Jhalawar district of Rajasthan. The benefits of Urea at 2% in terms of variations in the chlorophyll content, relative water contents in leaves, and maximum levels of leaf nitrogen and phosphorous emphasize its suitability in redressing nutrient deficiencies in acidic soils. This, in turn, will bode well for improving agricultural productivity and soil quality in general (Olivares et al. 2012; Hernandez and Olivares, 2019; Hernandez et al. 2020).

Leaf nutrient analysis

3.11 Effect of N (%) of acid lime cv. Kagzi leaves:

The experiment was conducted on acid lime cv. Kagzi trees involved the application of different treatments, including Urea and Nano urea, through foliar application. The researchers measured the effect of these treatments on the final leaf nitrogen status of the acid lime trees after harvesting the fruits in December 2022.

The findings as well displayed in Figure 3 revealed that the treatment T4, the application of Urea at 2% resulted in the highest leaf nitrogen content with a value of 2.05%. The T3 treatment, which was the second best treatment, was comprised of Urea at 1.5%, and it had a leaf nitrogen level of 2.01%. Third most efficient treatment was T8, which had Nano urea at a rate of 2000 ppm and gave the result of 2.01% leaf N content. The elevated leaf nitrogen content of acid lime cv. Kagzi. To begin, the high rate of uptake of nitrogen from the applied foliar Urea and Nano urea treatments increased the amounts of nitrogen stored in leaves. In addition, the increased freedom of the nutrients in the plants allowed for nitrogen transport in the leaf tissues. Third, improved hydrolysis of urea and nitrogen release further increased the nitrogen content of the leaves. Finally, improved nitrogen absorption in the plants resulted in the formation of nitrogen-enriched organic compounds. The results obtained from this study are consistent with previous findings of other researchers like Bondada *et al*. (2001), El-Otmani *et al*. (2004) on clementine mandarin, Abdallah (2020), and Deparpanah (2017) in pomegranate citrus plants, which supports the positive impact of foliar Urea and Nano urea treatments on leaf nitrogen content in citrus plants.

From these findings, it can be inferred that the application of Urea, particularly at a higher concentration of 2%, had a more significant impact on increasing the leaf nitrogen status of the acid lime cv. Kagzi trees compared to the application of Nano urea at the given concentration. This suggests that Urea, when applied via foliar application, might be a more efficient nitrogen source for enhancing the nitrogen content in the leaves of the acid lime trees.

3.12 Effect on P (%) of acid lime cv. Kagzi leaves:

The paragraph discusses the effects of foliar application of Urea and Nano urea treatments on acid lime cv. Kagzi trees, specifically focusing on their impact on leaf phosphorous (P) content. According to the results presented in Figure 4, it was observed that both Urea and Nano urea treatments led to an increase in leaf phosphorous content in the acid lime cv. Kagzi trees. The highest leaf phosphorous content (0.153%) was recorded in the T_4 treatment group, which involved the application of Urea at a concentration of 2.0%. Interestingly, the T_8 treatment group, using Nano urea at a concentration of 2000 ppm, showed an equivalent leaf phosphorous content of 0.153% to that of the T_4 treatment. The data displayed in Figure 5 provides evidence that both Urea and Nano urea treatments are effective in augmenting the leaf phosphorous content in the acid lime cv. Kagzi trees. It suggests that the foliar application of these treatments can be beneficial in enhancing the phosphorous uptake and assimilation in the leaves, which can potentially contribute to improved plant growth, health, and fruit production. The increase in leaf phosphorus (P) content of acid lime cv. Kagzi can be attributed to indirect biochemical and physiological processes in the plants. The application of foliar Urea and Nano urea likely stimulated root growth and activity due to increased nitrogen availability. Healthy and active roots play a crucial role in nutrient uptake, including phosphorus. Additionally, the metabolism of urea in plants and the subsequent production of ammonia (NH_3) may raise the pH in the vicinity of the urea-treated leaves, creating a slightly alkaline environment. This alkaline environment stimulates the activity of certain phosphatase enzymes responsible for breaking down organic phosphorus in the soil, making inorganic phosphorus more available for uptake by the roots and subsequent transportation to the leaves. These results are consistent with the findings reported by Abdallah (2020).

Effect on K (%) of acid lime cv. Kagzi leaves:

The results presented in Figure 5 indicate that the application of foliar spray treatments containing both Urea and Nano urea on Kagzi lime trees led to a consistent decrease in leaf potassium content across all the treatments. This reduction in leaf potassium content was observed when comparing the values after the application of the treatments to the initial values before the treatments were administered. The significant reduction in leaf potassium content in both the Urea and Nano urea treatments implies that these foliar spray treatments had an impact on the uptake, translocation, or utilization of potassium within the Kagzi lime trees. The decrease in leaf potassium levels suggests that either the applied nutrients (Urea and Nano urea) directly influenced the potassium levels or induced physiological responses in the trees that affected potassium uptake and distribution. The finding of a consistent decrease in leaf potassium content across all treatments suggests that both Urea and Nano urea treatments might have similar effects on the potassium status of the Kagzi lime trees. The reduction in leaf potassium (K) status of acid lime cv. Kagzi may be a result of nutrient allocation changes after fruit harvest. The trees may reallocate nutrients that were previously allocated to fruit development and growth towards other parts of the trees, including leaves. This redirection of nutrients leads to a decrease in overall nutrient content in the leaves, including potassium. Additionally, the increased nitrogen levels from the foliar Urea and Nano urea treatments may interfere with the uptake of potassium, contributing to the relative reduction in leaf potassium content. These findings are supported by the research conducted by Kumar *et al*. (1994) and Nava *et al*. (2010).

4. CONCLUSION AND RECOMMENDATION:

In a study comparing the effects of foliar application of Urea and Nano urea on acid lime cv. Kagzi trees in Vertisols of Jhalawar district, the T4 treatment using Urea at a 2.0% concentration was found to be the superior choice for enhancing various aspects of the acid lime trees. This treatment led to notable improvements in quality attributes, particularly an increase in the fruit's ascorbic acid content, which enhances its nutritional value. Additionally, the T4 treatment positively impacted the physiological aspects of the trees, promoting growth, vigor, and overall health compared to other treatments. These findings suggest that the T4 treatment has the potential to enhance the appeal and nutritional value of the acid lime fruit while contributing to the overall well-being and resilience of the trees.

In conclusion, this study elucidates the scientific relevance of Urea and Nano urea applications on Kagzi lime in Vertisols, offering insights into the optimization of cultivation methods. The observed superiority of 2% Urea treatment not only contributes to the knowledge base on citrus cultivation but also holds implications for improving soil quality and productivity in tropical agricultural fruit areas, particularly in Latin America (Olivares et al. 2018; Rodriguez et al. 2013; Montenegro et al. 2021; Viloria et al. 2023).

REFERENCES:

1. Abdallah, H. R. (2020) Effect of foliar application with urea, benzyl adenine and dry yeast on flowering and fruiting of Minneola Tangelo trees to reduce the severity of alternate bearing phenomena. *Middle East Journal*, **9**(4): 893-933.
2. Abdel-Salam, M. (2018) Response of lettuce (*Lactuca sativa* L.) to foliar spray using nano-urea combined with mycorrhiza. *Journal of Soil Sciences and Agricultural Engineering*, **9**(10): 467-472.
3. Al-Obeed, R. S., Ahmed, M. A. A., Kassem, H. A. and Al-Saif, A. M. (2018) Improvement of Kinnow mandarin fruit productivity and quality by urea, boron and zinc foliar spray. *Journal of Plant nutrition*, **41**(5): 609-618.
4. Anonymous (2021-22) Area and Production of Horticultural crops for 2021-22 (third advance estimate) *Ministry of Agriculture and Farmers Welfare*, *New Delhi*.
5. Araya-Alman, M., Olivares, B., Acevedo-Opazo, C. et al. (2020). Relationship Between Soil Properties and Banana Productivity in the Two Main Cultivation Areas in Venezuela. J Soil Sci Plant Nutr.; 20 (3): 2512-2524. https://doi.org/10.1007/s42729-020-00317-8
6. Bondada, B. R., Syvertsen, J. P. and Albrigo, L. G. (2001) Urea nitrogen uptake by citrus leaves. *HortScience*, **36**(6): 1061-1065.
7. Carpenter, S., Jain, M. C., Singh, J., Bhatnagar, P. and Arya, C. K. (2019) Effect of foliar spray of gibberellic acid and urea on yield and quality of guava (*Psidium guajava* L.) cv. L-49. *International Journal of Chemical Studies*, **7**(1): 205-207.

8. Chouhan, A., Sonkar, P. and Anjanawe, S. R. (2018) Effect of foliar application of urea, boron and 2,4-D in acid lime (*Citrus aurantifolia* Swingle) under Malwa Plateau conditions. *Bulletin of Environment, Pharmacology and Life Sciences*, **7**(1): 41-44.
9. Calero, J., Olivares, B.O., Rey, J.C., Lobo, D., Landa, B.B., Gómez, J. A. (2022). Correlation of banana productivity levels and soil morphological properties using regularized optimal scaling regression. Catena,; 208: 105718. https://doi.org/10.1016/j.catena.2021.105718
10. Campos, B. O. (2023). Banana Production in Venezuela: Novel Solutions to Productivity and Plant Health. Springer Nature. https://doi.org/10.1007/978-3-031-34475-6
11. Devarpanah, S., Tehranifar, A., Davarynejad, G., Aran, M., Abadía, J. and Khorassani, R. (2017) Effects of foliar nano-nitrogen and urea fertilizers on the physical and chemical properties of pomegranate (*Punica granatum* cv. Ardestani) fruits. *Hort Science*, **52**(2): 288-294.
12. Debaje, P. P., Shinde, E. P. and Ingale, H. V. (2011) Effect of plant growth regulators and nutrients on quality of acid lime (*Citrus aurantifolia* Swingle). *Asian Journal of Horticulture*, **6**(1): 253-255.
13. Dhaliwal, H. S. and Rohela, N. (2016) Influence of foliar application of urea and GA3 on chlorophyll content and nutritional status of rough lemon (*Citrus jambhiri* Lush.) seedlings under modified environment conditions. *Biochemical and Cellular Archives*, **16**(2): 285-289.
14. El-Otmani, M., Ait-Oubahou, A., Lovatt, C. J., El-Hassainate, F. and Kaanane, A. (2004) Effect of Gibberellic Acid, Urea and KNO_3 on Yield and on Composition and Nutritional Quality of Clementine Mandarin Fruit Juice. *Acta Horticulturae*, **632**(19): 149-158.
15. El-Otmani, M., Ait-Oubahou, A., Zahra, F. and Lovatt, C. J. (2002) Efficacy of foliar urea as an N source in sustainable citrus production systems. *Acta Horticulturae*, **594**(1): 611-617.
16. El-Tanany, M. M. and Abdel-Messih, M. N. (2009) Effect of foliar application with urea on flowering, fruiting and leaf nitrogen content of Valencia orange trees. *Journal of Agricultural Science Mansoura University*, **34**(8): 8915-8926.
17. Hernández, R. Olivares, B. (2019). Ecoterritorial sectorization for the sustainable agricultural production of potato (Solanum tuberosum L.) in Carabobo, Venezuela. Agricultural Science and Technology. 20(2): 339-354. https://doi.org/10.21930/rcta.vol20_num2_art:1462
18. Hernández, R., Olivares, B., (2020). Application of multivariate techniques in the agricultural land's aptitude in Carabobo, Venezuela. Tropical and Subtropical Agroecosystems, 23(2):1-12. https://n9.cl/zeedh
19. Hernandez, R., Olivares, B., Arias, A, Molina, JC., Pereira, Y. (2020). Eco-territorial adaptability of tomato crops for sustainable agricultural production in Carabobo, Venezuela. Idesia. 38(2):95-102. http://dx.doi.org/10.4067/S071834292020000200095
20. Hernández, R; Olivares, B. Arias, A; Molina, JC., Pereira, Y. (2018a). Agroclimatic zoning of corn crop for sustainable agricultural production in Carabobo, Venezuela. Revista Universitaria de Geografía.,. 27 (2): 139-159. https://n9.cl/l2m83
21. Hernández, R; Olivares, B., Arias, A; Molina, JC., Pereira, Y. (2018b). Identification of potential agroclimatic zones for the production of onion (Allium cepa L.) in Carabobo, Venezuela. Journal of the Selva Andina Biosphere., 6 (2): 70-82. http://www.scielo.org.bo/pdf/jsab/v6n2/v6n2_a03.pdf
22. Jat, G., and Laxmidas, K. H. (2014). Response of guava to foliar application of urea and zinc on fruit set, yield and quality. *Journal of AgriSearch*, **1**(2): 86-91.

23. Kolota E. and Osinska M. (2001): Efficiency of foliar nutrition of field vegetables grown at different nitrogen rates. In: Proc. IC Environ. Probl. N-Fert. *Acta Horticulturae*., 563: 87–91.
24. Kumar, R., Singh, R., Kumar, R. and Singh, R. (1994) Effect of various levels of nitrogen on leaf nutrient composition of apple (*Malus pumila* Mill.) cv. Red Delicious. *Recent Horticulture* **1**(1): 49-51.
25. Ladaniya, M.S., Marathe, R.A., Das, A.K., Rao, C.N., Huchche, A. D., Shirgure, P.S. and Murkute, A.A. (2020) High density planting studies in acid lime (*Citrus aurantifolia* Swingle). *Scientia Horticulturae.* 261, 108935
26. Lakshmipathi, Adiga, J. D., Kalaivanan, D., Mohana, G. S. and Meena, R. K. (2015) Effect of foliar application of micronutrients on reproductive growth of cashew (*Anacardium occidentale* L.) under south west coast region of Karnataka, India. *Trends in Biosciences*, **8**(2):447-449.
27. Lasa, B., Menendez, S., Sagastizabal, K., Cervantes, M. E. C., Irigoyen, I., Muro, J. and Ariz, I. (2012) Foliar application of urea to "Sauvignon Blanc" and "Merlot" vines: doses and time of application. *Plant Growth Regulation*, **67**(1):73-81.
28. Lobo, D; Olivares, B; Rey, J.C; Vega, A; Rueda-Calderón, A. Relationships between the Visual Evaluation of Soil Structure (VESS) and soil properties in agriculture: A meta-analysis. Scientia agropecuaria, 2023; 14 - 1, 67 - 78. https://doi.org/10.17268/sci.agropecu.2023.007
29. Lopez-Beltran, M., Olivares, B., Wolf-Lujan, D. (2019). Changes in land use and vegetation in the agrarian community of Kashaama, Anzoátegui, Venezuela: 2001-2 Geographical Journal Of Central America. 2(63):269-291. https://doi.org/10.15359/rgac.63-2.10
30. Mohammadi, H. and Khezri, M. (2018) The influence of foliar application of urea, zinc chelate and boric acid on growth characteristics, photosynthesis and survival of date palm offshoots (*Phoenix dactylifera*) cv. Mazafati. *European Journal of Horticultural Science*, **83**(2):114-120.
31. Montenegro, E., Pitti-Rodríguez, J, Olivares-Campos, B. 2021. Identification of the main subsistence crops of Teribe: a case study based on multivariate techniques. Idesia (Arica),; 39(3), 83-94. https://dx.doi.org/10.4067/S0718-34292021000300083
32. Nava, G., Dechen, A. R., Basso, C., Nachtigall, G. R. and Katsurayama, J. M. (2010) Mineral composition of leaves and growth of Fuji apple trees in response to nitrogen and potassium fertilization. *Agropecuária Catarinense,* **23**(1): 77-83.
33. Olivares B, Rey JC, Lobo D, Navas-Cortés JA, Gómez JA, Landa BB. (2022b). Machine Learning and the New Sustainable Agriculture: Applications in Banana Production Systems of Venezuela. Agricultural Research Updates. 42, 133 - 157. Nova Science Publishers, Inc
34. Olivares B, Vega A, Calderón MAR, Rey JC, Lobo D, Gómez JA, Landa BB. (2022a). Identification of Soil Properties Associated with the Incidence of Banana Wilt Using Supervised Methods. Plants, 11(15):2070. https://doi.org/10.3390/plants11152070
35. Olivares, B. (2016). Description of soil management in agricultural production systems in the Hamaca de Anzoátegui sector, Venezuela. La Granja: Life Sciences Magazine. 23(1): 14–24. https://n9.cl/ycp08
36. Olivares, B. O., & Franco, E. (2015). Agrosocial diagnosis of the indigenous community of Kashaama: An empirical study in the state of Anzoátegui, Venezuela. William of Ockham Magazine, 13(1), 87-95.
37. Olivares, B., Hernández, R; Coelho, R., Molina, JC., Pereira, Y. (2018). Spatial analysis of the water index: advances in sustainable decision-making in Carabobo agricultural territories, Venezuela Revista Geográfica de América Central. 60 (1): 277-299. DOI:

https://doi.org/10.15359/rgac.60-1.10
38. Olivares, B., Parra, R., Cortez, A. and Rodriguez, M.F. (2012). Patterns of rainfall homogeneity in climatic stations of the Anzoátegui state, Venezuela. Multiscience Journal. 12 (Extraordinary): 11-17. https://n9.cl/xbslq
39. Prasad, H., Thakur, M., Gupta, A. K. and Prasad, D. (2015) Effect of foliar application of 2, 4-D, urea and zinc sulphate on fruit drop, yield and fruit quality of Kinnow Mandarin. *International Journal of Bio-resource and Stress Management*, **6**(5): 619-622.
40. Rathore, R. S. and Chandra, A. (2003). Effect of application of nitrogen in combination with zinc sulphate on vegetative growth characteristics of acid lime (*Citrus aurantifolia* Swingle) cv. Kagzi lime. *Agricultural Science Digest*, **23**(3): 220-222.
41. Rey, J.C.; Olivares, B.O.; Perichi, G.; Lobo, D. (2022). Relationship of Microbial Activity with Soil Properties in Banana Plantations in Venezuela. Sustainability 14, 13531. https://doi.org/10.3390/su142013531
42. Rodríguez, M.F, Olivares, B., Cortez, A., Rey, J.C. and Lobo, D. (2015). Natural physical characterization of the indigenous community of Kashaama for the purposes of sustainable land management. Acta Nova. 7 (2):143-164. https://n9.cl/hakdx
43. Rodriguez, M.F., Cortez, A., Olivares, B., King, J.C., Vine, R., Wolf, D. (2013). Spatio-temporal analysis of precipitation in the state of Anzoátegui and its surroundings. Tropical Agronomy 63(1-2): 57-65. https://n9.cl/14iow
44. Rokaya, P., Baral, D., Gautam, D., Shrestha, A. and Paudyal, K. (2019) Effects of foliar application of urea and micronutrients on yield and fruit quality of mandarin (*Citrus reticulata* Blanco). *Journal of Agriculture and Forestry University*, **3**(1): 63-68.
45. Sadasivam, S. and Manickam, A. (1997). *Biochemical Methods*. New Age International. New Delhi, p:413.
46. Saleem, B. A., Malik, A. U., Maqbool, M., Islam-ud-din, M. F. and Rajwana, I. A. (2008) Early winter spray of low biuret urea improves marketable yield and fruit quality of sweet oranges. *Pakistan Journal of Botany*, **40**(4): 1455-1465.
47. Sawale, P. V., Patil, M. B., Tummod, A. R. and Pavhane, S. B. (2021) Effect of nutrients on growth & physical attributes of acid lime (*Citrus aurantifolia* L.) cv. Sai Sharbati. *The Pharm Innovation Journal*, **10**(11): 2063-2066.
48. Senjam, B. D. and Singh, S. R. (2021) Effects of foliar spray of NAA, 2, 4-D and urea on fruit yield and quality of *Citrus limon* L. Burm. cv. Assam lemon. *Bangladesh Journal of Botany*, **50**(1): 189-194.
49. Thakur, R.K., Baghel S.S., Sharma, G.D., Sahu, R.K. and Amule, P.C. (2012). Advances in Agro technologies for improving soil, plant and atmosphere systems. Laboratory Manual, pp: 19-24.
50. Viloria, J; Olivares, B. et al. 2023. Mapping Projected Variations of Temperature and Precipitation Due to Climate Change in Venezuela. Hydrology, 10, 96. https://doi.org/10.3390/hydrology10040096
51. Witte C.P., Tiller S.A., Taylor M.A. and Davies H.V. (2002): Leaf urea metabolism in potato. Urease activity profile and patterns of recovery and distribution of 15N after foliar urea application in wild-type and urease-antisense transgenics. *Plant Physiol*., 128: 1129–1136.
52. Yadav, A., Kanwar, J., Dubey, R. and Upadhyay, M. (2020) Effect of foliar application of urea, zinc sulphate and borax in flowering, fruiting and yield of acid lime (*Citrus aurantifolia* Swingle.) var. Kagzi lime under Malwa plateau conditions. *Journal of Pharmacognosy and Phytochemistry*, **9**(2): 483-485
53. Yildirim, E., Guvenc, I., Turan, M. and Karatas, A. (2007). Effect of foliar urea

application on quality, growth, mineral uptake and yield of broccoli (*Brassica oleracea* L. var. italica). *Plant Soil and Environment*, *53*(3), 120.

Table 2. Physico-chemical characteristics of acid lime cv. Kagzi fruits in response to foliar application of Urea and Nano urea treatments

Treatments	Fruit wt.(g.)	Fruit length(mm)	Fruit breadth (mm)	Juice (%)	TSS(ºbrix)	Acidity (%)	TSS/Acidity ratio	Ascorbic Acid (mg/100ml)	Juice pH
T_0	40.89	41.76	40.87	38.34	9.30	7.25	1.27	44.56	2.22
T_1	44.73	43.53	42.09	47.55	9.93	6.98	1.45	53.21	2.32
T_2	48.09	43.63	43.06	46.25	10.26	7.05	1.41	54.38	2.35
T_3	51.46	44.48	44.68	49.66	10.28	6.88	1.46	60.31	2.38
T_4	67.90	52.72	47.36	51.19	10.46	6.47	1.65	61.89	2.40
T_5	40.56	41.24	40.53	46.05	10.28	6.56	1.47	48.54	2.22
T_6	45.85	43.29	42.43	47.36	10.07	6.66	1.46	51.36	2.22
T_7	48.42	43.52	43.13	46.90	10.28	6.68	1.55	55.65	2.24
T_8	52.68	45.70	46.35	49.21	10.15	6.53	1.56	57.75	2.28
SEm(±)	1.41	0.97	0.78	0.68	0.15	0.05	0.02	0.45	0.02
CD 5%	4.25	2.92	2.36	2.06	0.47	0.17	0.06	1.35	0.06

Where: T_0 (water spray), T_1 (Urea @ 0.5%), T_2 (Urea @ 1.0%), T_3 (Urea @ 1.5 %), T_4 (Urea @ 2 %), T_5 (Nano urea @ 500 ppm), T_6 (Nano urea @1000 ppm), T_7 (Nano urea @ 1500ppm) and T_8 (Nano urea 2000ppm) are applied foliar treatments.

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FIG.1 Effect of foliar Urea and Nano urea treatments on chlorophyll content of acid lime cv. kagzi leaves

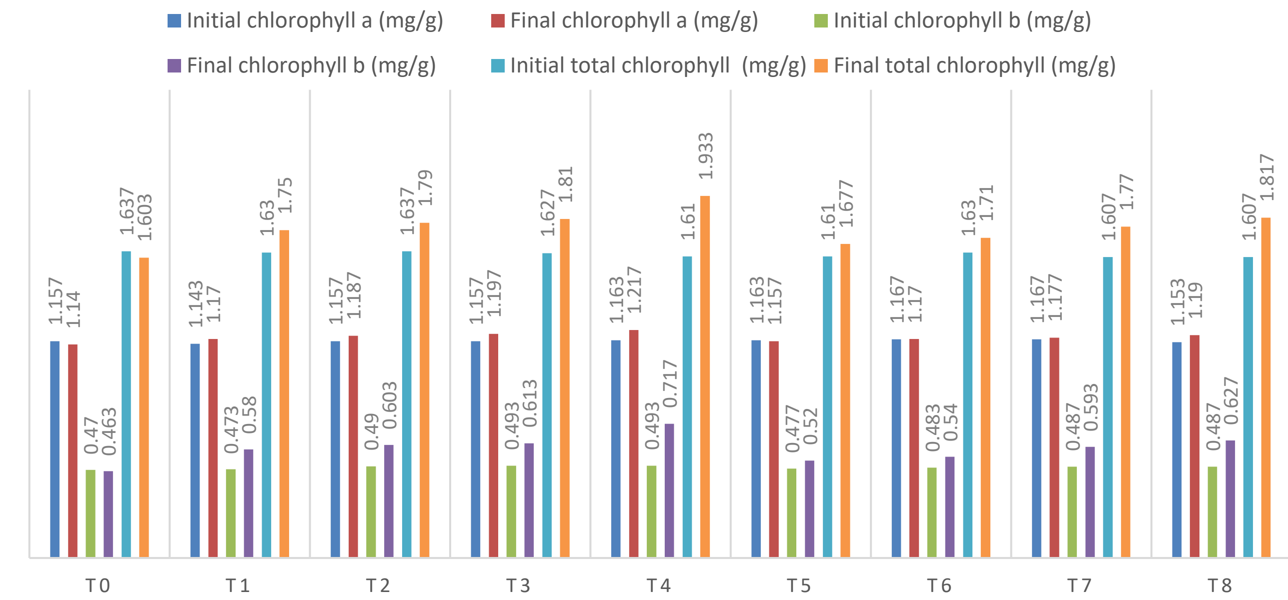
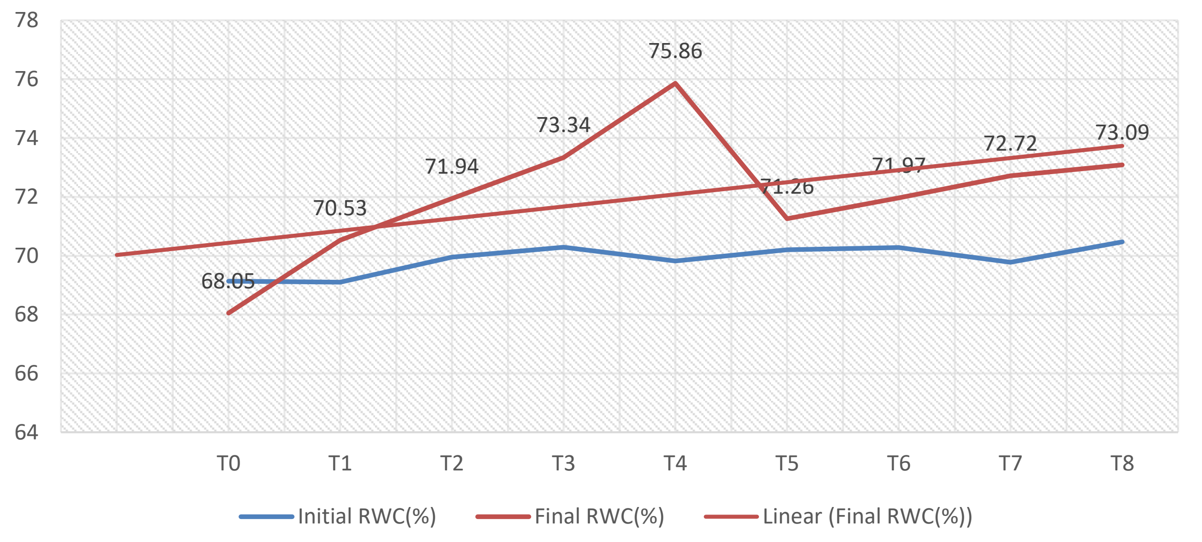


Fig.2 Effect of foliar Urea and Nano Urea treatments on Relative water content(%) of acid lime cv.Kagzi leaves



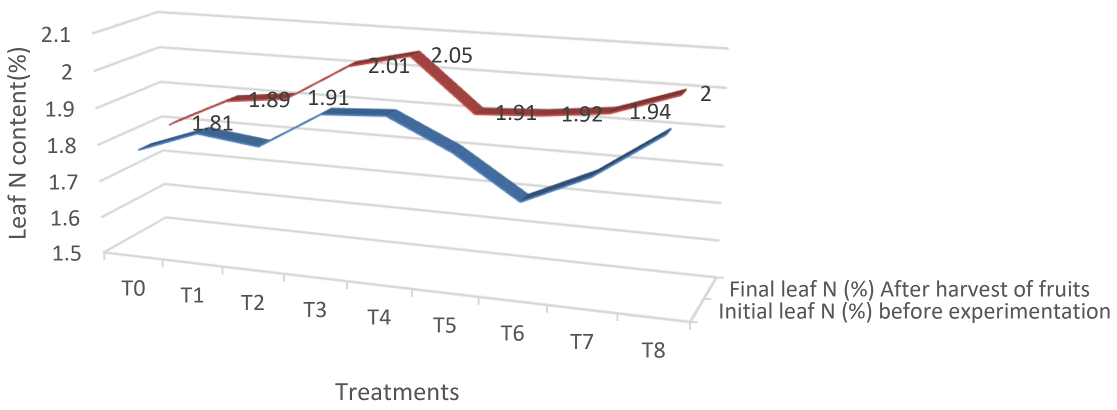


Fig.3 Effect of Foliar urea and Nano urea on leaf nitrogen content of acid lime cv.Kagzi

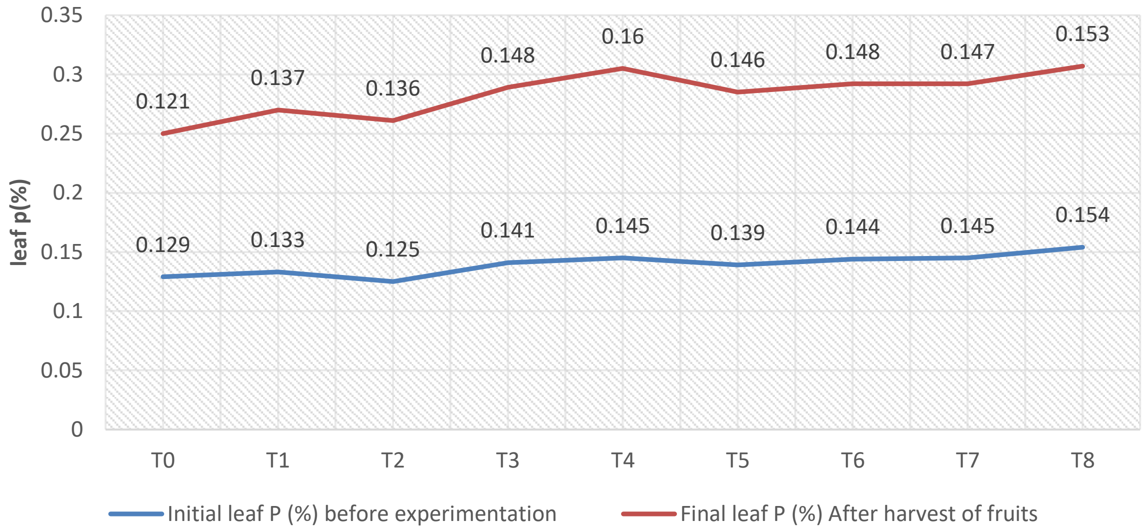
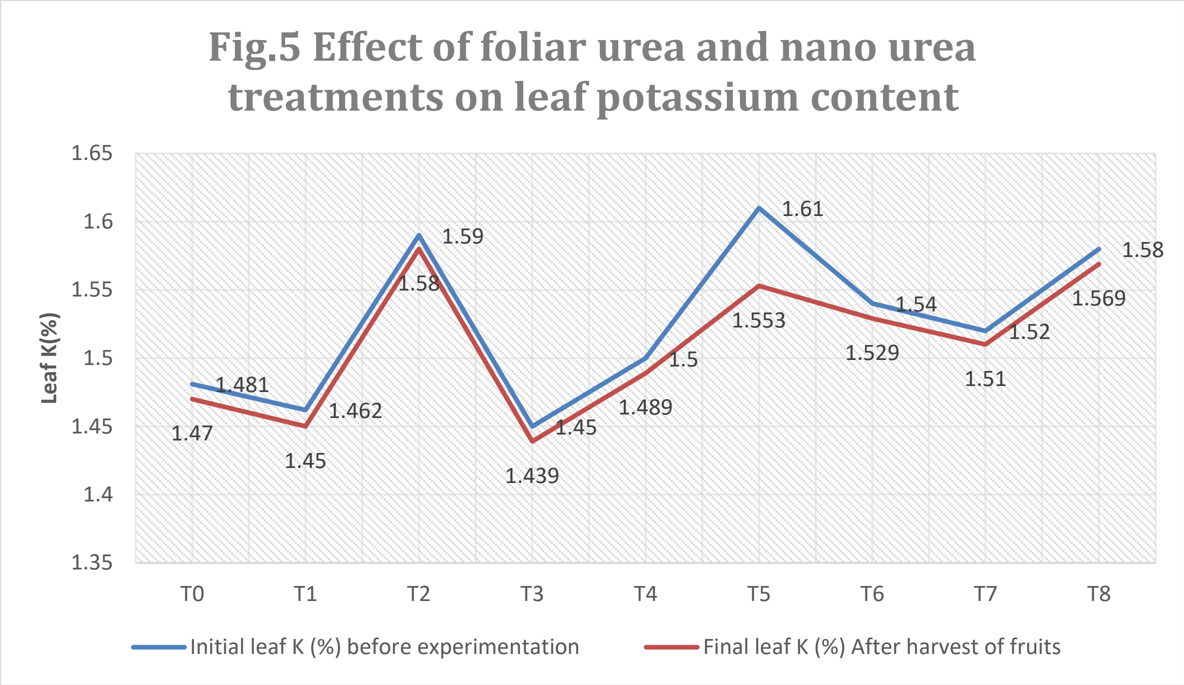


Fig.4 Effect of foliar urea and Nano Urea treatments on leaf phosphorous content of acid lime cv.kagzi



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