

## IMPACT OF NANO FERTILIZERS AND CHEMICAL FERTILIZERS ON VALENCIA ORANGE (*CITRUS SINENSIS* [L.] OSBECK) GROWTH, YIELD AND FRUIT QUALITY

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**Abstract.** This study was carried out in a private orchard located in Biala, Kafr El-Sheikh governorate, Egypt to investigate the effect of Nano-fertilizers versus chemical fertilizers on the growth and productivity of Valencia orange. Two rates of Nano-fertilizers (11.45 and 19.8 g/tree) were applied to the soil, foliar, or mixed, resulting in six treatments, with chemical fertilizers (0.55, 0.12, 0.46 Kg of N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O/tree/year, respectively) serving as the control. When compared to the control, Nano-fertilizer treatments increased tree canopy volume, leaf area, chlorophyll and nutrient contents, yield, and fruit quality. T7 (19.8 g/tree- half soil and half foliar application) produced consistent results in both seasons of the study, recording the highest canopy volume, leaf area, chlorophyll and nutrient content, yield, and fruit quality, which included vitamin C and TSS. Nano-foliar application was found to be more effective than soil application.

**Keywords:** citrus, nutrient use efficiency, nanotechnology, pollution, sustainability, vitamin C

### Introduction

Valencia oranges (*Citrus sinensis* [L.] Osbeck) are a significant group of late-maturity sweet orange varieties, which primarily grown for processing and orange juice production, as well as it is desirable for the fresh fruit markets due to its excellent taste and internal color.

Maintaining soil fertility and enhancing crop quality and yield depend heavily on nutrient fertilization. Because horticulture crops mostly rely on chemical fertilizers, precise nutrient management of these crops is a significant challenge on a global scale (Zulfiqar et al., 2019). Traditional fertilizers can be dangerous to people and the environment in addition to being expensive for the grower.

By 2050, it is predicted that there will be 9 billion people on the planet, necessitating a 70% increase in agricultural production worldwide. This cannot be done without increasing the use of fertilizer nutrients like NPK (Drescher et al., 2011). According to Tenkorang and Lowenberg- Deboer (2008) prediction, the world's demand for fertilizer nutrients (NPK) is anticipated to reach 324 million Mt in 2050.

It was estimated that around 40-90% of applied conventional fertilizers (N, P, K) is lost and could not reach the plant causing sustainable and economic losses (Trenkel, 1997; Ombodi and Saigusa, 2000; Solanki et al., 2015). This necessitates repeated application of such fertilizers, causing negative impact on soil and water pollution.

Scientists are under intense pressure to develop novel technologies that not only suit the productivity requirements of growers but also the financial budgets of both growers and the production business (Malhotra, 2016). Nanotechnology holds great promise for

sustainable agriculture practice, and it is expected to transform traditional farming practices into precision farming (Chhipa, 2017).

Nano-fertilizers are the most significant use of nanotechnology in agricultural crop production since they can feed plants gradually and under regulated conditions, unlike conventional fertilizers. When compared to chemical fertilizers, these Nano-fertilizers can be more effective in reducing soil pollution and other environmental problems (Naderi et al., 2011; Cui et al., 2010). Such characteristics of nanoparticles can be attributed to their high surface area/volume ratio, high solubility, high mobility and low toxicity (Sasson et al., 2007). The ability to apply Nano-fertilizers in smaller quantities than conventional fertilizers is one of their benefits.

In the context of sustainable agriculture, Nano-fertilizers are one of the new emerging agri-technologies and becoming progressively important in modern agriculture as alternative to traditional chemical fertilizers in last decades as ecofriendly (El-Saadony et al., 2021), showing encouraging results in various crops. However, the majority of studies on Nano-fertilizers, especially on fruit trees investigated the effect of a single element i.e. N on pomegranate (Aran et al., 2017); Zn and B on pomegranate (Davarpanah et al., 2016); Zn on grape (El-Said et al., 2019) and (Zagzog and Gad, 2017).

Therefore, this study was carried out to investigate the impact of using macro-element Nano-fertilizers (N, P, and K) as a complete fertilization program in comparison to chemical fertilizers and as a potential substitute in Valencia oranges.

## Materials and methods

This study was carried out during seasons of 2017 and 2018 on 19-year-old Valencia orange trees that were planted at 4 × 4 m apart, surface irrigated and grown in clay soil (Table 1) in Biala, Kafr El-Sheikh governorate, Egypt (31°09'58.9"N 31°12'47.9"E). Twenty-one trees were selected as uniform as possible in size and vigor to be used in this experiment.

**Table 1.** Experimental soil physical and chemical properties

| Particle distribution (%) |     |                         |                  |                 |                | Texture class                 | Bulk density (g/cm3)          | Field capacity (%) | Organic matter (%)            |                                |       |     |
|---------------------------|-----|-------------------------|------------------|-----------------|----------------|-------------------------------|-------------------------------|--------------------|-------------------------------|--------------------------------|-------|-----|
| Sand                      |     | Silt                    |                  | Clay            |                |                               |                               |                    |                               |                                |       |     |
| 7.5                       |     | 36.6                    |                  | 55.9            |                | Clay                          | 1.35                          | 41                 | 2.26                          |                                |       |     |
| EC ds/m                   | pH  | Soluble cations (meq/l) |                  |                 |                | Soluble anions (meq/l)        |                               |                    |                               | Available macro elements (ppm) |       |     |
| 1.6                       | 8.2 | Ca <sup>2+</sup>        | Mg <sup>2+</sup> | Na <sup>+</sup> | K <sup>+</sup> | CO <sub>3</sub> <sup>2-</sup> | HCO <sub>3</sub> <sup>-</sup> | Cl <sup>-</sup>    | SO <sub>4</sub> <sup>2-</sup> | N                              | P     | K   |
|                           |     | 4.0                     | 4.1              | 8.9             | 0.20           | 0.0                           | 4.0                           | 10.7               | 2.7                           | 58.1                           | 345.8 | 8.7 |

Presented values are average of three depths 0-30, 30-60 and 60-90 cm. Soil analysis were determined by using soluble soil saturation extract according to Wilde et al. (1985)

Two types of fertilizers were used; commercial mineral fertilizers, which was used as a control and Nano-fertilizers. The mineral fertilizers were soil applied as recommended by the Egyptian ministry of agriculture (0.55, 0.12, 0.46 Kg of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O/tree/year, respectively) and served as the control. The Nano-fertilizers were added in two rates (11.45 and 19.8 g/tree/time) either to the soil, foliar or mixed (half of the rate to the soil and the other half as foliar spray). Three combinations of Nano-fertilizers were used according to growth stage along the growing season. At the beginning of vegetative growth balanced Hyber Feed (19:19:19), at flowering stage Hyber Feed Drip

(6:40:12) and Solo (10:8:36) after fruit set. The number of addition times was twelve time/tree/year of the three Nano-forms.

The applied treatments were as follows:

T1: Control: commercial NPK mineral fertilizers (Soil application)

T2: 11.45 g/tree Nano-NPK fertilizer (Soil application)

T3: 19.8 g/tree Nano-NPK fertilizer (Soil application)

T4: 11.45 g/tree Nano-NPK fertilizer (Foliar spray application)

T5: 19.8 g/tree Nano-NPK fertilizer (Foliar spray application)

T6: 11.45 g/tree Nano-NPK fertilizer (half soil application and half foliar spray)

T7: 19.8 g/tree Nano-NPK fertilizer (half soil and application and half foliar spray)

### **Canopy volume**

Tree canopy volume (CV) was estimated according to the *Equation 1*:

$$CV = 0.528 \times H \times D^2 \quad (\text{Eq.1})$$

where, H = tree height, D = tree diameter (Castle, 1983).

### **Leaf area**

Leaf area was measured using a portable laser leaf area meter (CI-202, CID Bio Science Inc. U.S.A.).

### **Chlorophyll content**

Leaf chlorophyll content was determined using SPAD-501 leaf chlorophyll meter (Minolta Co. Ltd., Osaka, Japan).

### **Tree nutritional status**

Leaf nitrogen, phosphorus and potassium contents were determined according to Black (1965), Snell and Snell (1967) and Jackson (1973), respectively. Micronutrients including Fe, Zn and Mn concentrations were measured using atomic absorption spectrophotometry.

### **Fruit weight and yield**

Fruit weight was measured at harvest using an electronic balance, and yield/tree was estimated.

### **Fruit quality**

At harvest fruit titratable acidity was assayed by the titration method and expressed as percentage of citric acid (AOAC, 1995); TSS was measured using a digital refractometer; Vitamin C (L-Ascorbic acid) was determined according to Jacobs (1951).

### **Statistical analysis**

The used experimental design was a randomized block design with three replicates and the obtained data were subjected to statistical analysis using the analysis of variance (Snedecor and Cochran, 1981). Means comparison was performed using Least Significant Differences test (LSD) at 5% level of probability.

## Results and discussion

In the context of sustainable agriculture, it is vital to conduct from a practical research to produce new fertilizers with high nutrition efficiency and being ecologically friendly in order to replace the current conventional macronutrient fertilizers. Considering that conventional fertilizer use efficiencies are estimated to be 30-35%, 18-20%, and 35-40% for N, P, and K, respectively, with the remaining of applied fertilizers not reaching the plant and being lost to the environment (Trenkel, 1997; Momin and Joshi, 2015; Lassaletta et al., 2014; Sohair et al., 2018; Ombodi and Saigusa, 2000). Utilizing special characteristics of nanoparticles with dimensions ranging from 1 to 100 nm, nanofertilizers are designed to increase the efficiency with which nutrients are used (Suppan, 2017).

### Canopy volume

Data in Table 2 show that tree growth expressed in canopy volume increased significantly due to Nano-fertilizers application compared to the control, which recorded the lowest volume (15.33 and 17.93, in both seasons, respectively). Considering the effectiveness of different Nano-fertilizers rate and type of application, T7 showed the highest significant canopy volume (21.15 and 25.1 in both seasons, respectively), while T2 the recorded the lowest canopy volume; although this treatment has the same rate used in T4 but it seems that foliar application have a positive effect on tree growth than soil application. The effect also found between T3 and T5. This may be due the effect of soil condition of the availability of nutrients to the plant roots.

**Table 2.** Effect of Nano and chemical fertilizers on tree canopy volume, leaf area and chlorophyll content of Valencia oranges

| Treatments  | Canopy volume (m <sup>3</sup> ) | Leaf area (cm <sup>2</sup> ) | Chlorophyll content SPAD |
|-------------|---------------------------------|------------------------------|--------------------------|
| <b>2017</b> |                                 |                              |                          |
| T1          | 15.33 f                         | 144.22 g                     | 119.00 e                 |
| T2          | 16.80 e                         | 151.22 f                     | 123.24 d                 |
| T3          | 19.47 c                         | 163.06 c                     | 126.64 bc                |
| T4          | 17.44 d                         | 154.09 e                     | 123.43 d                 |
| T5          | 20.18 b                         | 166.99 b                     | 127.76 b                 |
| T6          | 19.55 c                         | 155.34 d                     | 124.30 cd                |
| T7          | 21.15 a                         | 169.36 a                     | 135.00 a                 |
| <b>2018</b> |                                 |                              |                          |
| T1          | 17.93 f                         | 143.86 f                     | 115.25 e                 |
| T2          | 19.75 e                         | 151.67 e                     | 121.35 d                 |
| T3          | 22.48 c                         | 163.95 c                     | 134.04 a                 |
| T4          | 21.08 d                         | 154.7 d                      | 124.32 c                 |
| T5          | 23.78 b                         | 166.14 b                     | 130.40 b                 |
| T6          | 23.37 b                         | 155.21 d                     | 125.02 c                 |
| T7          | 25.1 a                          | 170.02 a                     | 134.73 a                 |

T1: The control (commercial mineral fertilizers); T2: Nano NPK fertilizer at 11.45 g/tree., via soil application; T3: Nano NPK fertilizer at 19.8 g/tree., via soil application; T4: Nano NPK fertilizer at 11.45 g/tree., via foliar spray; T5: Nano NPK fertilizer at 19.8 g/tree., via foliar spray; T6: Nano NPK fertilizer at 11.45 g/tree., divided into two equal doses (half soil application and half foliar spray); T7: Nano NPK fertilizer at 19.8 g/tree., divided to two equal doses (half soil application and half foliar spray). Means followed with the same letter are not significantly different at 5% level by LSD

These findings are consistent with those of Hagagg et al. (2018a, b), Roshdy and Refaai (2016), Tarafdar et al. (2014), and Salama (2012). They reported overall growth improvement of studied plants as a result of using Nano-fertilizers.

### Leaf area

Leaf area showed a remarkable increase as a result of Nano-fertilizers usage (Table 2). The control treatment (T1) showed the smallest leaf area, and the highest area resulted by T7, followed by T5 and T3, respectively. These results are supported by Roshdy and Refaai (2016), who found that Nano-fertilizers significantly enhanced the leaf area of date palm.

### Chlorophyll content

Leaf chlorophyll content elevated significantly under Nano-fertilizers treatment compared to the control, following the same pattern as the tree canopy and leaf area (Table 2). Higher contents were recorded under high rates of application (19.8 g/tree) and mixed (soil and foliar) compared to one type of application. This improvement in chlorophyll content was found in various crops due to Nano-fertilizers application (Ghafariyan et al., 2013; Salama, 2012; Tarafdar et al., 2014; Roshdy and Refaai, 2016; Rajput et al., 2021a).

### Tree nutritional status

The applied Nano treatments showed a significant increment in leaf content of macro-elements (N, P and K) compared to the control, however, T7 treatment outperformed the other treatments (Table 3).

**Table 3.** Effect of Nano and chemical fertilizers leaf mineral contents (N, P, K, Zn, Fe, Mn) of Valencia oranges

| Treatments  | N %     | P %    | K %     | Zn ppm   | Fe (ppm)  | Mn (ppm)  |
|-------------|---------|--------|---------|----------|-----------|-----------|
| <b>2017</b> |         |        |         |          |           |           |
| T1          | 2.14 d  | 0.12 d | 0.84 c  | 60.00 f  | 288.33 e  | 126.33 d  |
| T2          | 2.52 c  | 0.16 c | 1.20 b  | 66.00 d  | 333.33 d  | 137.66 c  |
| T3          | 2.69 bc | 0.22 b | 1.34 b  | 71.33 b  | 373.66 b  | 144.66 ab |
| T4          | 2.54 c  | 0.20 b | 1.28 b  | 64.00 e  | 347.33 cd | 140.66 bc |
| T5          | 2.83 ab | 0.26 a | 1.38 b  | 72.66 ab | 360.00 bc | 146.00 a  |
| T6          | 2.68 bc | 0.22 b | 1.41 ab | 69.00 c  | 351.00 c  | 142.66 ab |
| T7          | 2.92 a  | 0.26 a | 1.62 a  | 74.00 a  | 391.66 a  | 146.33 a  |
| <b>2018</b> |         |        |         |          |           |           |
| T1          | 2.11 c  | 0.13 d | 1.00 d  | 59.33 c  | 294.66 f  | 123.66 d  |
| T2          | 2.47 b  | 0.19 c | 1.18 cd | 66.66 b  | 331.00 e  | 140.66 c  |
| T3          | 2.84 a  | 0.23 b | 1.47 ab | 72.66 a  | 375.00 b  | 144.00 bc |
| T4          | 2.44 b  | 0.22 b | 1.29 bc | 66.00 b  | 345.33 de | 141.33 c  |
| T5          | 2.86 a  | 0.26 a | 1.45 ab | 73.00 a  | 361.00 bc | 148.33 a  |
| T6          | 2.49 b  | 0.23 b | 1.42 ab | 68.33 b  | 348.66 cd | 142.66 c  |
| T7          | 2.77 a  | 0.27 a | 1.58 a  | 73.33 a  | 397.33 a  | 148.00 ab |

T1: The control (commercial mineral fertilizers); T2: Nano NPK fertilizer at 11.45 g/tree., via soil application; T3: Nano NPK fertilizer at 19.8 g/tree., via soil application; T4: Nano NPK fertilizer at 11.45 g/tree., via foliar spray; T5: Nano NPK fertilizer at 19.8 g/tree., via foliar spray; T6: Nano NPK fertilizer at 11.45 g/tree., divided into two equal doses (half soil application and half foliar spray); T7: Nano NPK fertilizer at 19.8 g/tree., divided to two equal doses (half soil application and half foliar spray). Means followed with the same letter are not significantly different at 5% level by LSD

T7 and T5 had the highest nitrogen content in the first season, while there was no significant difference between the higher rate (19.8 g) of application treatments (T3, T5, T7).

In case of leaf phosphorus content, T7 and T5 recorded the highest content without significant difference between these two treatments. In terms of potassium content, T7 was the highest, but there was no significant difference between it and T6 in the first season, and T3, T5, and T6 in the second season. The control treatment showed the least values of macro-elements content.

The same effect was found in terms of micro-elements (Zn, Fe and Mn), where a significant increase occurs due to Nano-fertilizers application compared to the control. T7 and T5 exhibited the highest Zn and Mn contents and in case on Fe content T7 showed superior effect.

Such improvement in leaf nutritional status was found by Roshdy and Refaai (2016) on date palm and in Washington Navel orange due to foliar nan-potassium application (Hafez et al., 2018).

### ***Fruit weight and yield***

There was a significant increase in fruit weight under different Nano-fertilizer treatments compared to the control, and the highest fruit weight was found under T7, resulting in the highest yield under the same treatment in both seasons (*Fig. 1*).

The increased yield can be attributed to improved nutrient availability, which leads to improved tree nutritional status, leaf chlorophyll content, and a higher assimilation rate.

The improved yield as a result to nano-fertilizers application was similarly reported by Morteza et al. (2013), Tarafdar et al. (2014), Davarpanah et al. (2016, 2017), Roshdy and Refaai (2016), Zagzog and Gad (2017), Sohair et al. (2018), Zulfiqar et al. (2019), and El-Saadony et al. (2021).

### ***Fruit quality***

Total soluble solids (TSS) content increased significantly as a result of Nano-fertilizers application, with the highest content at T7 in both seasons, followed by T5 in the first season, and T5 and T3 in the second season. While, the control had the lowest value (*Fig. 2*).

The juice acidity had the same trend of TSS, leading to higher TSS/acid ratio under the control, followed by T2 and T4 in the first season and with T2, T4, T6 in the second season, with no significant difference.

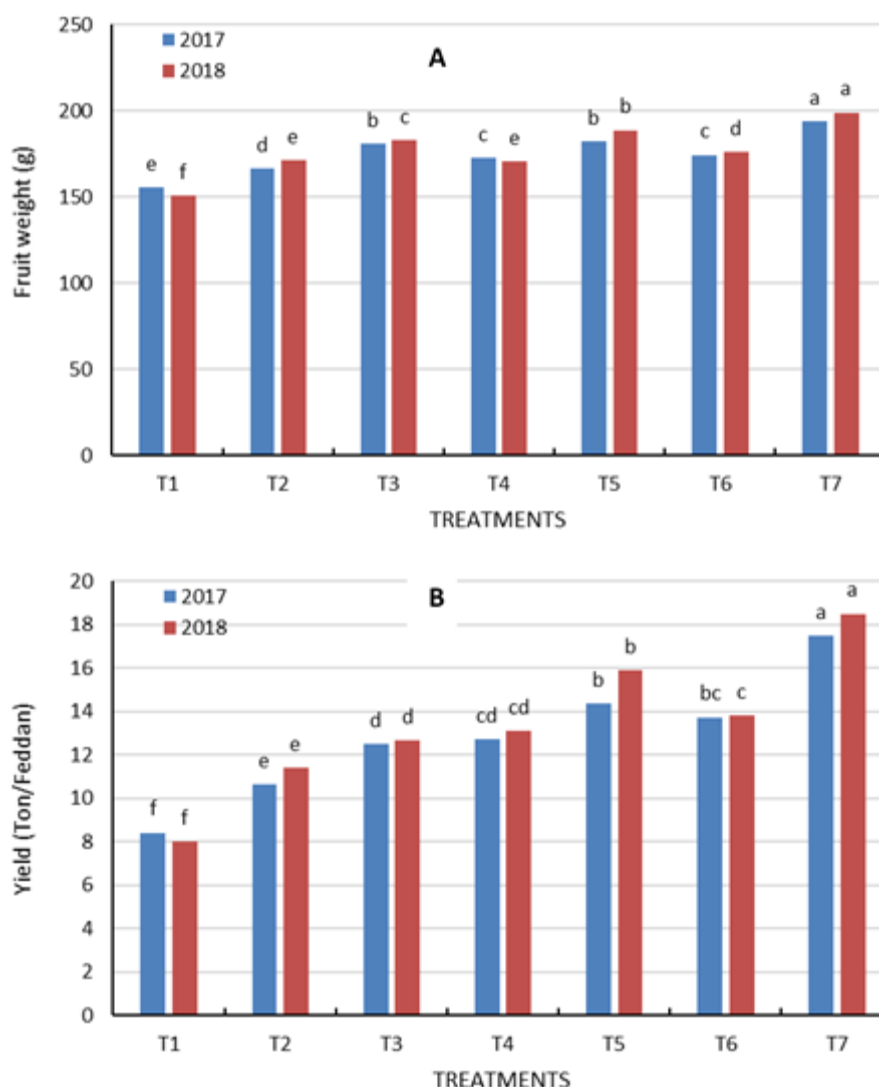
Ascorbic acid content (Vitamin C) was the highest under T7, meanwhile other nano-treatment showed higher contents than the control (*Fig. 3*).

Roshdy and Refaai (2016) found that Nano-fertilizers had a positive impact on date palm fruit quality parameters when compared to conventional fertilizers. Foliar spraying pomegranates with Nano-nitrogen, zinc, and boron significantly improved fruit quality parameters such as TSS and acidity (Davarpanah et al., 2016, 2017). Moreover, vitamin C and TSS was enhanced in Washington Navel orange due to Nano-potassium foliar application (Hafez et al., 2018) as well as in mango due to Nano-zinc application (Zagzog and Gad, 2017).

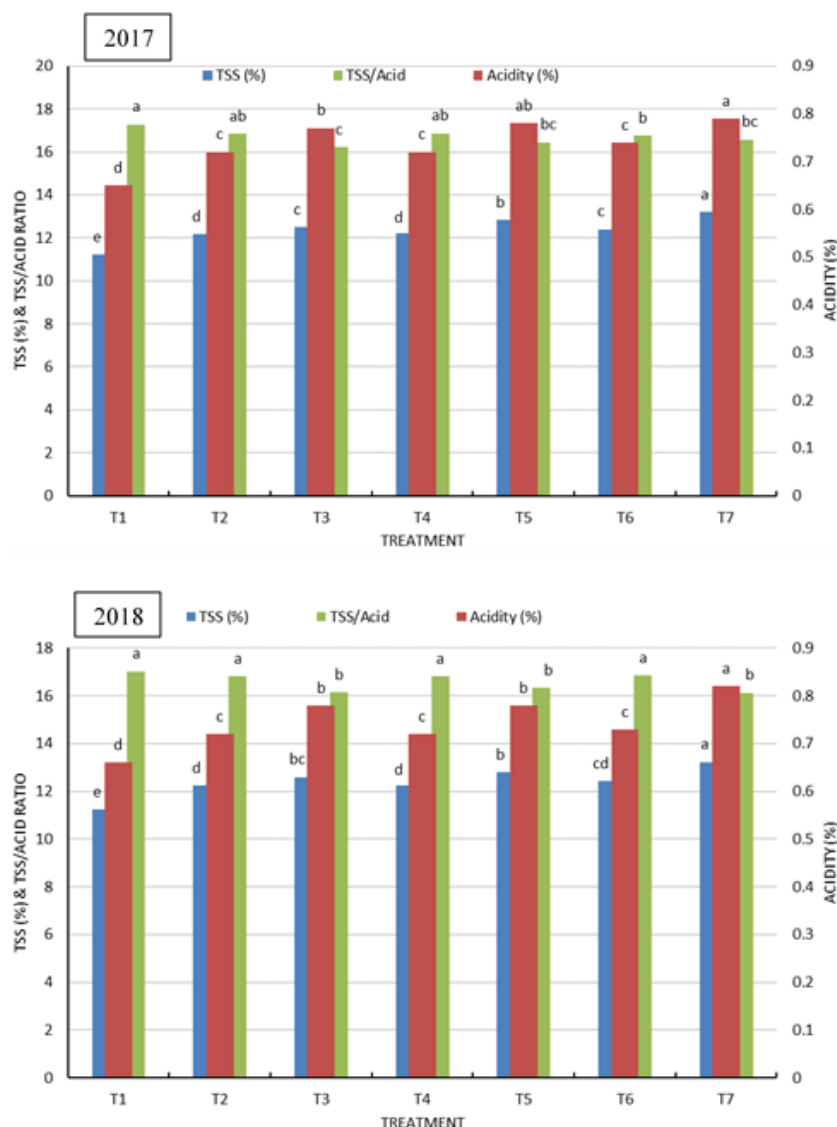
The positive effect of Nano-fertilizers maybe due to facilitating beneficial functions for the nitrogen cycle, enhanced enzyme activities and stimulating soil plant-friendly microbes (Verma et al., 2022a). Furthermore, nanomaterials, can provide a slow, steady,

and time-dependent release of essential nutrients, represent an opportunity to improve nutrients use efficiency (Jyothi and Hebsur, 2017; Preetha and Balakrishnan, 2017; Kalia and Sharma, 2019; Mejias et al., 2021).

Considering that nano-fertilizers applied to the soil have extended availability (40-50 days to release nutrients fully) to the plant in the soil compared to the chemical fertilizers (4-10 days) (Subramanian and Rahale, 2009; Brady and Weil, 1999; Chen and Wei, 2018; Adisa et al., 2019; Seleiman et al., 2021), this is due to the higher surface tension of Nanoparticles on the surface of fertilizers particles than that of chemical fertilizer.



**Figure 1.** Effect of Nano and chemical fertilizers on fruit weight (A) and yield (B) of Valencia oranges. T1: The control (commercial mineral fertilizers); T2: Nano NPK fertilizer at 11.45 g/tree., via soil application; T3: Nano NPK fertilizer at 19.8 g/tree., via soil application; T4: Nano NPK fertilizer at 11.45 g/tree., via foliar spray; T5: Nano NPK fertilizer at 19.8 g/tree., via foliar spray; T6: Nano NPK fertilizer at 11.45 g/tree., divided into two equal doses (half soil application and half foliar spray); T7: Nano NPK fertilizer at 19.8 g/tree., divided into two equal doses (half soil application and half foliar spray). 1 feddan = 1.04 acres. Means followed with the same letter are not significantly different at 5% level by LSD



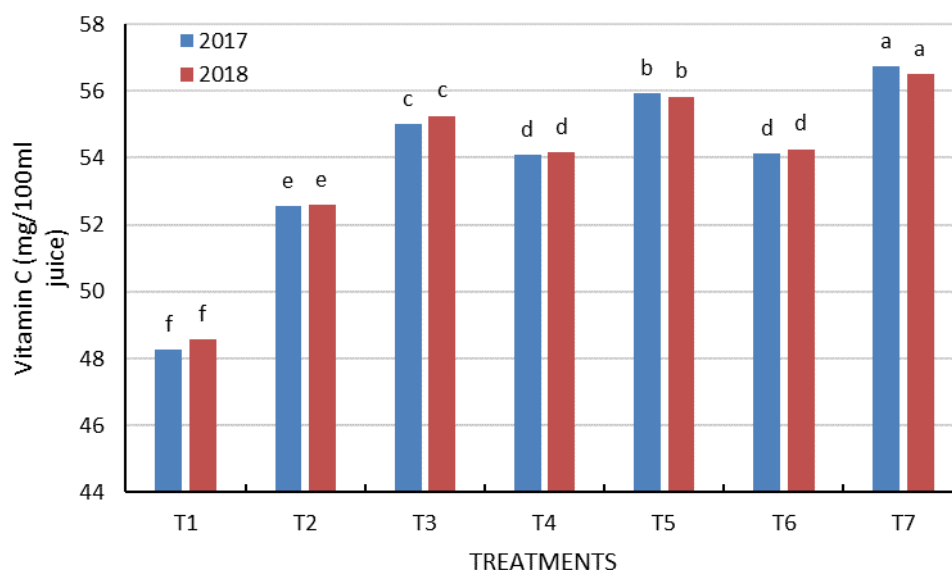
**Figure 2.** Effect of Nano and chemical fertilizers on TSS, Acidity and TSS/Acid ratio of Valencia oranges. T1: The control (commercial mineral fertilizers); T2: Nano NPK fertilizer at 11.45 g/tree., via soil application; T3: Nano NPK fertilizer at 19.8 g/tree., via soil application; T4: Nano NPK fertilizer at 11.45 g/tree., via foliar spray; T5: Nano NPK fertilizer at 19.8 g/tree., via foliar spray; T6: Nano NPK fertilizer at 11.45 g/tree., divided into two equal doses (half soil application and half foliar spray); T7: Nano NPK fertilizer at 19.8 g/tree., divided to two equal doses (half soil application and half foliar spray). Means followed with the same letter are not significantly different at 5% level by LSD

All of this increases chlorophyll formation, photosynthesis rate, dry matter production, plant productivity and overall growth (Salama, 2012; Pirvulescu et al., 2015; Rajput et al., 2021a), which associated with upgraded leaf capacity to capture sunlight, RuBisCO activity, photosynthetic CO<sub>2</sub> assimilation (Gao et al., 2006; Yang and Hong, 2006; Janmohammadi et al., 2016; Fellet et al., 2021), plant performance, nitrogen metabolism, and soluble proteins (Verma et al., 2022b).

Because the efficacy of fertilizers to the soil can be influenced by a variety of factors, including soil characteristics (type, PH, organic matter, CEC, etc.) and the interaction



with other minerals during the absorption process (Hussain et al., 2019), the differences in exposure route can be explained.



**Figure 3.** Effect of Nano and chemical fertilizers on vitamin C content of Valencia oranges. T1: The control (commercial mineral fertilizers); T2: Nano NPK fertilizer at 11.45 g/tree., via soil application; T3: Nano NPK fertilizer at 19.8 g/tree., via soil application; T4: Nano NPK fertilizer at 11.45 g/tree., via foliar spray; T5: Nano NPK fertilizer at 19.8 g/tree., via foliar spray; T6: Nano NPK fertilizer at 11.45 g/tree., divided into two equal doses (half soil application and half foliar spray); T7: Nano NPK fertilizer at 19.8 g/tree., divided to two equal doses (half soil application and half foliar spray). Means followed with the same letter are not significantly different at 5% level by LSD

Several results indicated that foliar application has a greater effect on plant overall growth, where nutrients can be easily absorbed via stomata with reduced time lag between application and uptake by plant especially during the rapid growth stage (Benzon et al., 2015; Hafeez et al., 2015; Solanki et al., 2015; Abdel-Aziz et al., 2016; Eleyan et al., 2018; Sohair et al., 2018; Adisa et al., 2019; Abd El-Azeim et al., 2020; Rajput et al., 2021 a, b; Kalwani et al., 2022; Verma et al., 2022a).

## Conclusion

In general, nano-fertilizers treatments improved plant growth, nutritional status, yield, and fruit quality parameters when compared to the control. T7 (19.8 g/tree - half soil and half foliar application) is the recommended treatment, as it produced the best growth parameters, leaf nutritional status, yield, and fruit quality.

The obtained results indicate the possibility of using an integrated program of Nano-fertilizers as an alternative to chemical fertilizers, allowing for more efficient resource use, lower costs, and less environmental pollution. Meanwhile, increased yield, improved fruit quality, and the potential to increase growers' profit margins.

However, further studies are needed to explore the fate of these Nano-fertilizers on the whole agroecosystem, especially in the plant.

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