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

EL-SHEREIF, A. R.* – ZERBAN, S. M. – ELMAADAWY, M. I.

Horticulture Department, Faculty of Agriculture, Kafrelsheikh University, 33516 Kafr El-Sheikh, Egypt
(phone: +20-47-314-8387)

**Corresponding author*
e-mail: aelshereif@agr.kfs.edu.eg; phone: +20-100-939-4474

(Received 27th Oct 2022; accepted 6th Jan 2023)

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_2O_5, and K_2O/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

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_13751387

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)		
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	N	P	K
1.6	8.2	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_2O_5 and K_2O/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 spry). 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

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_13751387

(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*:

$$CV = 0.528 \text{ x } H \text{ x } D^2 \tag{Eq.1}$$

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

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_13751387

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^3)	Leaf area (cm^2)	Chlorophyll content SPAD
2017			
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
2018			
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

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_13751387

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)
2017						
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
2018						
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

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_13751387

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,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_13751387

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.

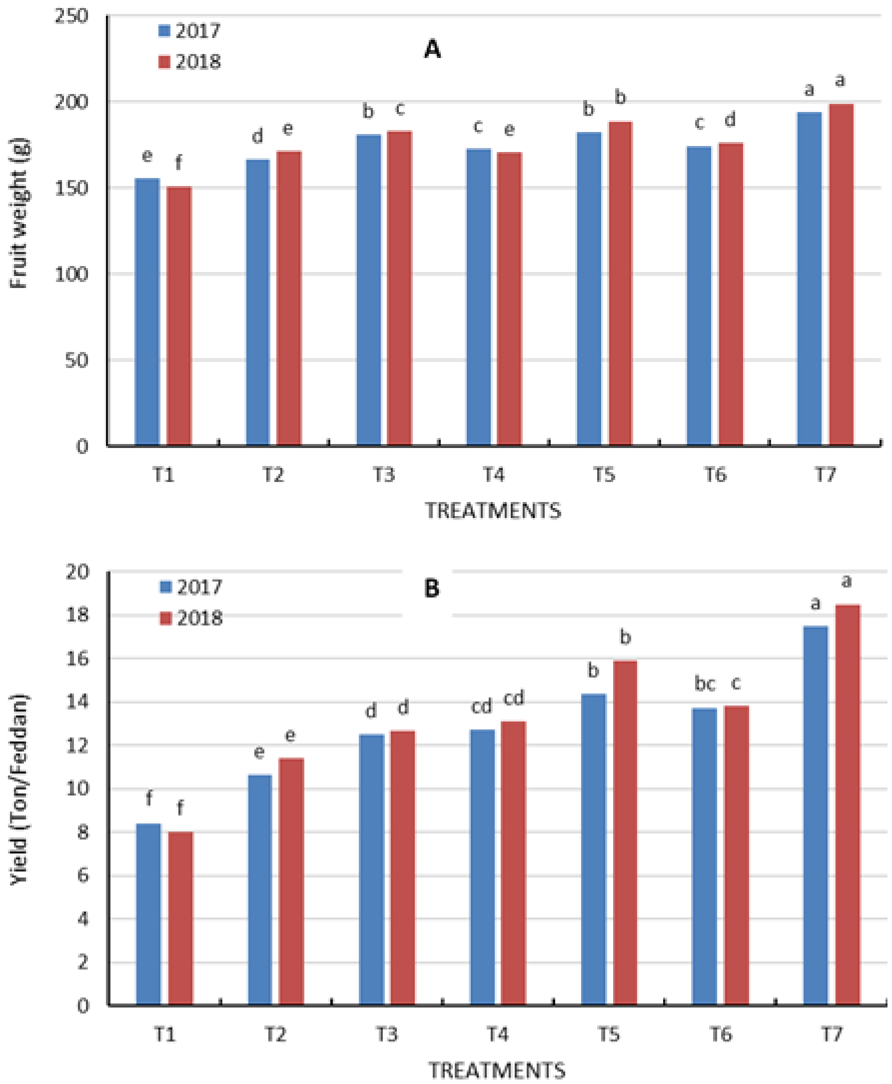

Figure 1. *Effect of Nano and chemical fertilizers on fruit weight (A) and yield (B) of Valencia oranges. T1: The control (commercial mineral fertilizers); T2: Nano NPK fertilizer at 11.45 g/tree., via soil application; T3: Nano NPK fertilizer at 19.8 g/tree., via soil application; T4: Nano NPK fertilizer 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 to 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*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_13751387

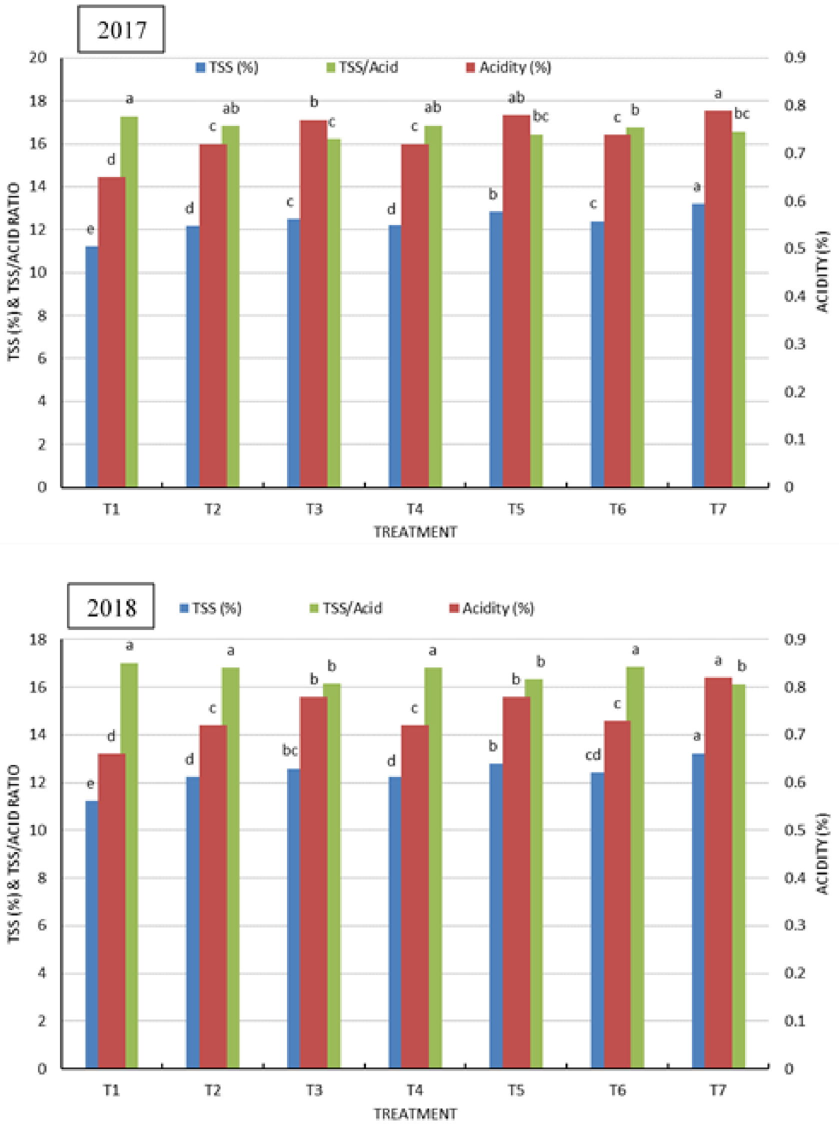

Figure 2. *Effect of Nano and chemical fertilizers on TSS, Acidity and TSS/Acid ratio of Valencia oranges. T1: The control (commercial mineral fertilizers); T2: Nano NPK fertilizer at 11.45 g/tree., via soil application; T3: Nano NPK fertilizer at 19.8 g/tree., via soil application; T4: Nano NPK fertilizer 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; Pirvulescua et al., 2015; Rajput et al., 2021a), which associated with upgraded leaf capacity to capture sunlight, RuBisCO activity, photosynthetic CO2 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

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_13751387

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

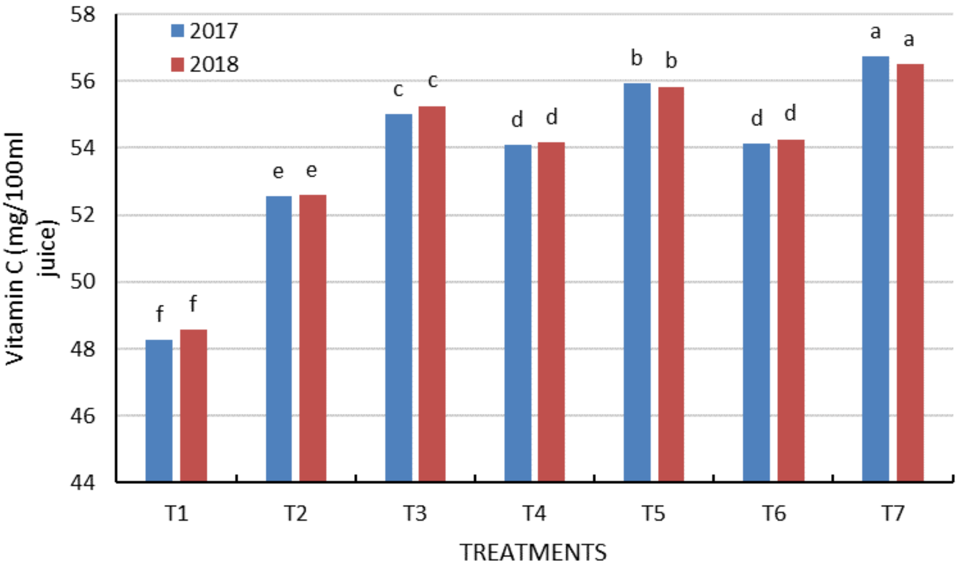

Figure 3. *Effect of Nano and chemical fertilizers on vitamin C content of Valencia oranges. T1: The control (commercial mineral fertilizers); T2: Nano NPK fertilizer at 11.45 g/tree., via soil application; T3: Nano NPK fertilizer at 19.8 g/tree., via soil application; T4: Nano NPK fertilizer at 11.45 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.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_13751387

REFERENCES

[1] Abd El-Azeim, M. M., Sherif, M. A., Hussien, M. S., Tantawy, I. A. A., Bashandy, S. O. (2020): Impacts of nano- and non-nanofertilizers on potato quality and productivity. – Acta Ecologica Sinica 40(5): 388-397. https://doi.org/10.1016/j.chnaes.2019.12.007.

[2] Abdel-Aziz, H. M. M., Hassaneen, M. N. A., Omer, A. M. (2016): Nano chitosan-NPK fertilizer enhances the growth and productivity of wheat plants grown in sandy soil, Span. – J. Agric. Res. 14: 1-9.

[3] Adisa, I. O., Pullagurala, V. L. R., Peralta-Videa, J. R., Dimkpa, C. O., Elmer, W. H., Gardea-Torresdey, J. L., et al. (2019): Recent advances in nano-enabled fertilizers and pesticides: a critical review of mechanisms of action. – Environ. Sci.: Nano. 6: 2002-2030. DOI: 10.1039/C9EN00265K.

[4] AOAC (1995): Official Methods of Analysis. 16th Ed. – Association of Official Analytical Chemists, Washington DC.

[5] Aran, M., Abadia, 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. DOI: 10.21273/HORTSCI11248-16.

[6] Benzon, H. R. L., Rubenecia, M. R. U., Ultra, V. U., Lee, S. C. (2015): Nanofertilizer affects the growth, development, and chemical properties of rice. – Int. J. Agron. Agric. Res. 7: 105-117. DOI: 10.5539/jas.v7n4p20.

[7] Black, C. A. (1965): Methods of Soil Analysis: Part I, Physical and Mineralogical Properties. – American Society of Agronomy, Madison, Wisconsin.

[8] Brady, N. C., Weil, R. R. (1999): The Nature and Properties of Soils. 12th Ed. – Prentice Hall Publishers, London, pp. 1-9, 453-536, 727, 739-740.

[9] Castle, W. (1983): Growth, yield and cold hardiness of seven-year-old ‘Bearss’ lemon on twenty-seven rootstocks. – Proc. Florida Sta. Hort. Soc. 96: 23-25.

[10] Chen, J., Wei, X. (2018): Controlled-Release Fertilizers as a Means to Reduce Nitrogen Leaching and Runoff in Container-Grown Plant Production. – In: Amanullah, A., Fahad, S. (eds.) Nitrogen in Agriculture - Updates. IntechOpen, London. https://doi.org/10.5772/intechopen.73055.

[11] Chhipa, H. (2017): Nanofertilizers and nanopesticides for agriculture. – Environ Chem Lett. 15: 15-22. DOI 10.1007/s10311-016-0600-4.

[12] Cui, H. X., Sun, C. J., Liu, Q., Jiang, J., Gu, W. (2010): Applications of nanotechnology in agrochemical formulation, perspectives, challenges and strategies. – In: International Conference on Nanoagri, Sao Pedro, Brazil, pp 28-33.

[13] Davarpanah, S., Tehranifar, A., Davarynejad, G., Abadía, J., Khorasani, R. (2016): Effects of foliar applications of zinc and boron nano-fertilizers on pomegranate (Punica granatum cv. Ardestani) fruit yield and quality. – Scientia Horticulturae 210: 57-64.

[14] Davarpanah, S., Tehranifar, A., Davarynejad, G., Mehdi, A., Abadía, J., Khorasani, 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: A Publication of the American Society for Horticultural Science 52(2): 288-294.

[15] Drescher, A., Glaser, R., Richert, C., Nippes, K. (2011): Demand for Key Nutrients (NPK) in the Year 2050. – University of Freiburg, Freiburg.

[16] Eleyan, S. E. D., Abodahab, A. A., Abdallah, A. M., Rabeh, H. A. (2018): Effect of nitrogen, phosphorus and potassium nano fertilizers with different application times, methods and rates on some growth parameters of Egyptian cotton (Gossypium barbadense L.). – Bioscience Research 15(2): 549-564.

[17] El-Saadony, M. T., Almoshadak, A. S., Shafi, M. E., Albaqami, N. M., Saad, A. M., El-Tahan, A. M., Desoky, E. M., Elnahal, A. S. M., Almakas, A., Abd El-Mageed, T. A., Taha, A. E., Elrys, A. S., Helmy, A. M. (2021): Vital roles of sustainable nano-fertilizers in improving plant quality and quantity-an updated review. – Saudi Journal of Biological Sciences 28: 7349-7359.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2102_13751387

[18] El-Said, R. E. A., El- Shazly, S. A., El-Gazzar, A. A. M., Shaaban, E. A., Saleh, M. M. S. (2019): Efficiency of nano-zinc foliar spray on growth, yield and fruit quality of flame seedless grape. – J. Applied Sci. 19: 612-617.
[19] Fellet, G., Pilotto, L., Marchiol, L., Braidot, E. (2021): Tools for nanoenabled agriculture: fertilizers based on calcium phosphate, silicon, and chitosan nanostructures. – Agronomy 11: 1239. DOI: 10.3390/agronomy1106 1239.
[20] Gao, F., Hong, F., Liu, C., Zheng, L., Su, M., Wu, X., et al. (2006): Mechanism of nano. Anatase TiO2 on promoting photosynthetic carbon reaction of spinach. – Biol. Trace Elem. Res. 111: 239-253. DOI: 10.1385/BTER:111:1:239.
[21] Ghafariyan, M. H., Malakouti, M. J., Dadpour, M. R., Stroeve, P., Mahmoudi, M. (2013): Effects of magnetite nanoparticles on soybean chlorophyll. – Environmental Science & Technology 47(18): 10645-10652. DOI: 10.1021/es402249b.
[22] Hafeez, A., Razzaq, A., Mahmood, T., Jhanzab, H. M. (2015): Potential of copper nanoparticles to increase growth and yield of wheat, J. – Nanosci. Adv. Technol. 1(1): 6-11.
[23] Hafez, O. M., Sultan, M., Ibrahim, S., Saleh, M. A. (2018): Enhancement yield and fruit quality of Washington Navel orange by application of spraying potassium microencapsulated biodegradable polylactic acid. – Agricultural Engineering International: CIGR Journal 19(5): 101-110.
[24] Hagagg, L. F., Mustafa, N. S., Genaidy, E. A. E., El-Hady, E. S. (2018a): Effect of spraying nano-NPK on growth performance and nutrients status for (Kalamat cv.) olive seedling. – Bioscience Research 15(2): 1297-1303.
[25] Hagagg, L. F., Mustafa, N. S., Shahin, M. F. M., El-Hady, E. S. (2018b): Impact of nanotechnology application on decreasing used rate of mineral fertilizers and improving vegetative growth of Aggizi olive seedlings. – Bioscience Research 15(2): 1304-1311.
[26] Hussain, A., Ali, S., Rizwan, M., Rehman, M. Z. U., Qayyum, M. F., Wang, H., Rinklebe, J. (2019): Responses of wheat (Triticum aestivum) plants grown in a Cd contaminated soil to the application of iron oxide nanoparticles. – Ecotoxicol. Environ. Saf. 173: 156-164.
[27] Jackson, M. L. (1973): Soil Chemical Analysis. – Prentice Hall of India Pvt Ltd, Delhi.
[28] Jacobs, M. B. (1951): The Chemical Analysis of Foods and Food Products. – D. Van. Nostrand, Inc. Now York, London, pp. 724-732.
[29] Janmohammadi, M., Amanzadeh, T., Sabaghnia, N., Dashti, S. (2016): Impact of foliar application of nano micronutrient fertilizers and titanium dioxide nanoparticles on the growth and yield components of barley under supplemental irrigation. – Acta Agric. Slov. 107: 265-276. DOI: 10.14720/aas.2016.107.2.01.
[30] Jyothi, T. V., Hebsur, N. S. (2017): Effect of nanofertilizers on growth and yield of selected cereals - a review. – Ag 38. DOI:10.18805/ag.v38i02.7942.
[31] Kalia, A., Sharma, S. P. (2019): Nanomaterials and Vegetable Crops: Realizing the Concept of Sustainable Production. – In: Pudake, R. N., Chauhan, N., Kole, C. (eds.) Nanoscience for Sustainable Agriculture. Springer International Publishing, Cham, pp. 323-353. DOI:10.1007/978-3-319-97852-9_15.
[32] Kalwani, M., Chakdar, H., Srivastava, A., Pabbi, S., Shukla, P. (2022): Effects of nanofertilizers on soil and plant-associated microbial communities: emerging trends and perspectives. – Chemosphere 287: 132107. DOI: 10.1016/j.chemosphere.2021.132107.
[33] Lassaletta, L., Billen, G., Grizzetti, B., Anglade, J., Garnier, J. (2014): 50 year trends in nitrogen use efficiency of world cropping systems: the relationship between yield and nitrogen input to cropland. – Environmental Research Letters, IOP Publishing 9(10): 1-9. ff10.1088/1748-9326/9/10/105011ff. ffhal-01194829f.
[34] Malhotra, S. K. (2016): Water soluble fertilizers in horticultural crops - an appraisal. – Ind. J. Agric. Sci. 86: 1245-1256.

[35] Mejias, J. H., Salazar, F., Pérez Amaro, L., Hube, S., Rodriguez, M., Alfaro, M. (2021): Nanofertilizers: a cutting-edge approach to increase nitrogen use efficiency in grasslands. – Front. Environ. Sci. 9:635114. DOI: 10.3389/fenvs.2021.635114.

[36] Momin, J. K., Joshi, B. H. (2015): Nanotechnology in Foods. – In: Rai, M. et al. (eds.) Nanotechnologies in Food and Agriculture. Springer International Publishing Cham. DOI 10.1007/978-3-319-14024-7_1.

[37] Morteza, E., Moaveni, P., Farahani, H. A., Kiyani, M. (2013): Study of photosynthetic pigments changes of maize (Zea mays L.) under nano TiO2 spraying at various growth stages. – Springer Plus 2: 1-5. DOI: 10.1186/2193-1801-2-247.

[38] Naderi, M., Danesh Shahraki, A. A., Naderi, R. (2011): Application of nanotechnology in the optimization of formulation of chemical fertilizers. – Iran J. Nanotech. 12: 16-23.

[39] Ombodi, A., Saigusa, M. (2000): Broadcast application versus band application of polyolefin-coated fertilizer on green peppers grown on andisol. – J. Plant Nutr. 23: 1485-1493.

[40] Pirvulescua, A., Salaa, F., Boldea, M. (2015): Variation of chlorophyll content in sunflower under the influence of magnetic nanofluids. – AIP Conf. Proc. 1648:670009. DOI: 10.1063/1.4912904.

[41] Preetha, P. S., Balakrishnan, N. (2017): A review of nano fertilizers and their use and functions in soil. – Int. J. Curr. Microbiol. App. Sci 6: 3117-3133. DOI:10. 20546/ijcmas.2017.612.364.

[42] Rajput, V. D., Singh, A., Minkina, T. M., Shende, S. S., Kumar, P., Verma, K. K., et al. (2021a): Potential Applications of Nanobiotechnology in Plant Nutrition and Protection for Sustainable Agriculture. – In: Ingle, A. P. (ed.) Nanotechnology in Plant Growth Promotion and Protection: Recent Advances and Impacts. Chap. 5. 1st Ed. John Wiley & Sons Ltd., Hoboken, NJ. DOI: 10.1002/9781119745884.ch5.

[43] Rajput, V. D., Singh, A., Minkina, T., Rawat, S., Mandzhieva, S., Sushkova, S., et al. (2021b): Nano-enabled products: challenges and opportunities for sustainable agriculture. – Plants 10: 2727. DOI: 10.3390/plants10122727.

[44] Roshdy, K. A., Refaai, M. M. (2016): Effect of nanotechnology fertilization on growth and fruiting of Zaghloul date palms. – J. Plant Production, Mansoura Univ. 7(1): 93-98.

[45] Salama, H. M. H. (2012): Effects of silver nanoparticles in some crop plants, Common bean (Phaseolus vulgaris L.) and corn (Zea mays L.). – Inter. Res. J. of Biote. 3(10): 190-197.

[46] Sasson, Y., Levy-Ruso, G., Toledano, O., Ishaaya, I. (2007): Nanosuspension: Emerging Novel Agrochemical Formulation. – In: Ishaaya, I., Horowwitz, A. R., Nauen, R. (eds.) Insecticides Design Using Advanced Technologies. Springer, Berlin, pp 1-39.

[47] Seleiman, M. F., Almutairi, K. F., Alotaibi, M., Shami, A., Alhammad, B. A., Battaglia, M. L. (2021): Nano-fertilization as an emerging fertilization technique: why can modern agriculture benefit from its use? – Plants 10: 2. DOI: 10.3390/plants10010002.

[48] Snedecor, G. W., Cochron, W. G. (1981): Statistical Methods. 7th Ed. – Iowa state Univ., Press, Ames, IA.

[49] Snell, F. D., Snell, C. T. (1967): Colorimetric Methods of Analysis. – D. Van Nostrand Company, New Jersey, pp: 551-552.

[50] Sohair, E. E. D., Abdall, A. A., Amany, A. M., Faruque, H. M., Houda, R. A. (2018): Evaluation of nitrogen, phosphorus and potassium nano-fertilizers on yield, yield components and fiber properties of Egyptian cotton (Gossypium barbadense L.). – J Plant Sci Crop Protec 1(3): 302.

[51] Solanki, P., Bhargava, A., Chhipa, H., Jain, N., Panwar, J. (2015): Nano-Fertilizers and Their Smart Delivery System. – In: Rai, M., Ribeiro, C., Mattoso, L., Duran, N. (eds.) Nanotechnologies in Food and Agriculture. Springer International, Cham, pp: 81-101.

[52] Subramanian, K. S., Rahale, C. S. (2009): Synthesis of nano-fertilizers formulations for balanced nutrition. – In: Proceedings of the Indian Society of Soil Science - Platinum Jubilee Celebration, 22-25 December, IARI, New Delhi.

[53] Suppan, S. (2017): Applying Nanotechnology to Fertilizer: Rationales, Research, Risks and Regulatory Challenges. – The Institute for Agriculture and Trade Policy, Brazil.

[54] Tarafdar, J. C., Raliya, R., Mahawar, H., Rathore, I. (2014): Development of zinc nanofertilizer to enhance crop production in pearl millet (Pennisetum americanum). – Agric Res 3: 257-262. https://doi.org/10.1007/s40003-014-0113-y.

[55] Tenkorang, F., Lowenberg-Deboer, J. (2008): Forecasting Long-term Global Fertilizer Demand. – Food and Agriculture Organization of the United Nations (FAO). Rome.

[56] Trenkel, M. E. (1997): Controlled-Release and Stabilized Fertilizers in Agriculture. – International Fertilizer Industry Association, Paris.

[57] Verma, K. K., Song, X. P., Joshi, A., Tian, D. D., Rajput, V. D., Singh, M., et al. (2022a): Recent trends in nano-fertilizers for sustainable agriculture under climate change for global good security. – Nanomaterials 12: 173. DOI: 10.3390/nano12010173.

[58] Verma, K. K., Song, X. P., Joshi, A., Rajput, V. D., Singh, M., Sharma, A., Singh, R. K., Li, D. M., Arora, J., Minkina, T., Li, Y. R. (2022b): Nanofertilizer possibilities for healthy soil, water, and food in future: an overview. – Front. Plant Sci. 13:865048. DOI: 10.3389/fpls.2022.865048.

[59] Wilde, S. A., Corey, R. B., Iyer, J. C., Voigt, G. K. (1985): Soil and Plant Analysis for Tree Culture. – Oxford and IBH Publishing Company, New Delhi, pp. 94-105.

[60] Yang, F., Hong, F. S. (2006): Influence of nano-anatase TiO2 on the nitrogen metabolism of growing spinach. – Biol. Trace Elem. Res. 110: 179-190. DOI: 10.1385/BTER:110:2:179.

[61] Zagzog, O. A., Gad, M. M. (2017): Improving growth, flowering, fruiting and resistance of malformation of mango trees using nano-zinc. – Middle East Journal of Agriculture 6(3): 673-681.

[62] Zulfiqar, F., Navarro, M., Ashraf, M., Akram, N. A., Munne-Bosch, S. (2019): Nanofertilizer use for sustainable agriculture: advantages and limitations. – Plant Sci. 289: 110270. DOI: 10.1016/j.plantsci.2019.1 10270.