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Effect of Different Forms of Microelements Foliar Application on Vegetative Growth of " Sukkari" Orange Citrus Trees

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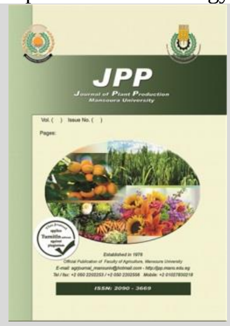

ABSTRACT

The performance of sweet orange (*Citrus sinensis* L.) were studied 40-year-old trees. The trees were spaced 6 meters apart and grown in clay soil with a drainage well, under a surface irrigation system. Different forms of foliar fertilization using microelements were studied in two consecutive seasons 2021 and 2022. The study aimed to know the effect of foliar fertilization with a mixture of iron (Fe), zinc (Zn), and manganese (Mn) in their nano, sulfur, and chelated forms. The leaves were sprayed at three different times: before flowering, after fruit set, and two weeks after fruit set. The results showed that chelated and nano fertilizers significantly enhanced the vegetative growth in Sukkari orange trees compared to mineral fertilizers. It is worth noting that chelated fertilizers produced the highest results, followed by nano fertilizers in second place. In contrast, mineral fertilizers resulted in the lowest vegetative growth characteristics during both seasons in Sukkari orange trees.

Keywords: microelements , foliar , vegetative , Sukkari , trees.

INTRODUCTION

Citrus fruits are among the most significant fruit crops worldwide in terms of growing area and production, and oranges are the main citrus crop in Egypt. Citrus fruits are economically significant in Egypt,.They play a vital role in the nation's fruit economy. Egypt is the world's sixth-largest producer of oranges and ranks first in terms of cultivation area and output. Among the economic crops exported, oranges (both sweet and bitter) are considered the primary citrus fruit according to Abobatta (2018). The total cultivated area of Citrus acreage reached 519.788 feddan, which produce about 4.708.427 tons according to Ministry of Agriculture (2022).

Micronutrients play crucial roles in the growth, development, and productivity of fruit trees. Even though they are required in smaller amounts compared to macronutrients (such as nitrogen, phosphorus, and potassium), micronutrients are essential for various physiological and biochemical processes in plants.

Mineral fertilizers are compounds utilized to enhance plant growth and boost productivity. They contain essential elements such as nitrogen, phosphorus, potassium, iron, zinc, manganese, and others that plants require. The application of mineral fertilizers depends on soil characteristics and the needs of the cultivated plants, and they come in various forms, including liquids, solids, and foliar fertilizers. Proper usage according to instructions and recommendations is crucial, as overuse can damage plants, soil, and the environment, potentially leading to groundwater, soil, river, and lake contamination.

Chelated fertilizers are a type of fertilizer that contains essential plant nutrients, such as iron, zinc, manganese, and copper that are chemically combined with an organic molecule to form a chelate. Chelates are organic molecules that bind to metal ions and form a stable, water-soluble complex that can be easily absorbed by plants. It has been found that using nutrients in chelated form is more effective than the traditional method (Bozary, 2012). They inhibit the formation of complexes with specific soil compounds and are water-soluble, allowing plants to absorb them when sprayed (Laishram and Baruah, 2020).

Nano fertilizers are an effective alternative to traditional fertilizers. Due to their outstanding structural properties and great efficacy, the use of nanomaterials as fertilizers has become a viable alternative to conventional fertilizers. Nanomaterials are highly functional and have distinct structural properties ranging in size from 1 to 100 nm. Since a few years ago, nano-fertilizers have attracted great attention in agricultural management (Fatima *et al*., 2020). Compared to bulk materials, nanoparticles have a high surface-to-volume ratio, which results in more active sites for absorption and adsorption (Sadak and Bakry 2020). The goal of creating fertilizers with nanoparticles is to provide plants with the nutrients they need efficiently without flooding the environment with excessive amounts of fertilizer (Boutchuen *et al*., 2019). Through precise nutrient management, nanotechnology has been researched to boost economic crop yields, decrease nutrient losses, and utilize fewer reactive chemicals in agriculture (Mali *et al*., 2020).

The primary aim of the study was to evaluate the effectiveness of microelements fertilizers in different forms, mineral, chelated, and nano, evaluating their effectiveness across various spraying schedules to determine the optimal form and timing for application.

MATERIALS AND METHODS

This study was conducted over two consecutive seasons (2022 and 2023) on 40-year-old sweet orange trees (Sukkari cultivar, *Citrus sinensis* L.) in a private orchard located in the village of Mit Lait Hashem, near the city of

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Mahalla Al-Kubra in Gharbia Governorate, Egypt. The trees were spaced 6 meters apart and grown in clay soil with a drainage well, under a surface irrigation system. Thirty sex trees were selected for the experiment, and they were almost homogeneous in appearance, shape, and size. All the trees were subjected to the same agricultural practices, such as fertilization, irrigation, and pest and weed control, as recommended by the Egyptian Ministry of Agriculture. The study aimed to investigate the effect of foliar spraying with a mixture of iron (Fe), zinc (Zn), and manganese (Mn) in their nano, sulfur, and chelated forms. The foliar sprays were applied at three different timings: before flowering, after fruit set, and two weeks after fruit set.

Experimental Design

A factorial experiment was used in a randomized completely block design with three replicates. The treatments were as follows:

a. First factor was foliar applications of iron, zinc, and manganese fertilizers with three forms (mineral, chelated, and nano).

b. Second factor was application frequency with four levels (spraying with tap water, once, twice, and thrice).

In both seasons, mixtures of iron sulfate, zinc sulfate, and manganese sulfate in mineral form were prepared, with each element weighing 0.5 grams. Similarly, mixtures of iron (Fe), zinc (Zn), and manganese (Mn) in chelated form were prepared, each also weighing 0.5 grams. Additionally, a nano form mixture of these elements was prepared, with each element at a concentration of 25 ppm. These treatments were compared to a control group where trees were sprayed only with water at the same application times. Spraying was carried out three times at a rate of 3 liters per tree: before flowering, after fruit set, and two weeks after fruit set. Aqueous solutions were prepared using tap water, with Tween 20 at 0.05% added as a wetting Data Collection:

A- Vegetative growth measurements:

In the seasons of this study, four secondary buds were well distributed around the circumference of each tree in four directions from the non-fruiting branches of the spring growth cycle and were labeled in April. The following vegetative traits were recorded at the beginning of June (two weeks after the last spraying) for each season:

Shoot length (cm): A ruler is used to measure the length of the shoot (cm).

B- Leaf characteristics:

A sample of 25 mature leaves was randomly collected at the beginning of June (two weeks after the last spraying) from each season of the fourth and fifth leaf from non-fruitless shoots of the spring growth cycle for each replicate to determine the following:

1-Leaf area (cm^2):

It was determined according to the following equation provided by **Chou (1966)**

Leaf area (cm^2) = (⅔) [length (cm) x width (cm)].

2- Leaf chlorophyll content:

Samples were randomly selected from the middle of the leaves to test the chlorophyll content using the CCM-200 Plus Chlorophyll Content Meter. This device measures chlorophyll content in leaves based on transmittance. The meter provides a Chlorophyll Content Index (CCI) value, which is proportional to the amount of chlorophyll in the sample. The CCI value is derived by measuring the transmittance at two wavelengths (CCI = % Transmittance at 931 nm / % Transmittance at 653 nm).

Statistical analysis

According to statistical analysis method stated by Gomez and Gomez (1984), the data were subjected to calculate the analysis of variance. According to Waller and Duncan (1969), the least significant differences test (LSD) was used to assess treatment mean differences at 5% probability. Statistic 8.1 was used to conduct all statistical analyses (Analytical Software, 2005).

RESULTS AND DISCUSSION

Shoot length (cm):

Table 1 illustrates the effects of foliar applications of iron, zinc, and manganese fertilizers (in mineral, chelated, and nano forms) and varying application frequencies (once, twice, or three times) on the shoot length of Sukkari orange trees across two seasons. The findings demonstrate that chelated and nano fertilizers significantly enhanced shoot length in Sukkari orange compared to mineral fertilizers. Notably, chelated fertilizers produced the highest shoot lengths (7.94 and 8.72cm), followed by nano fertilizers (7.10 and 7.92 cm). In contrast, mineral fertilizers resulted in the lowest shoot lengths (6.09 and 6.90 cm), respectively during both seasons.

Regarding the number of spray applications, Table 1 clearly shows that shoot length of Sukkari orange trees increased with more frequent spraying. The highest shoot length (9.29 and 10.37 cm) was recorded after three foliar applications, while the lowest (4.85 and 4.83 cm) was in unsprayed trees during both seasons, respectively. Similar findings were reported by El-Shazly and Dris (2004), who observed improved shoot length in Anna apple trees with foliar spraying of chelated micronutrients, likely due to enhanced carbohydrate accumulation and micronutrient restoration, achieving heights of up to 7.94 and 8.72 cm during 2022 and 2023 without negatively affecting fruit set. However, these results differ from those of El-Gioushy *et al.* (2021), who studied the effects of foliar spraying of Fe in chelated, nano, and mineral forms on Washington Navel Orange.

Considering the interaction effect between microelement fertilizer forms and the number of spray applications, Table 1 indicated that the highest shoot lengths were observed in trees sprayed three times with chelated forms, recording 11.10 and 12.17 cm, respectively, across the two seasons. In contrast, the lowest shoot lengths were found in unsprayed trees, recording 4.73 and 4.77 cm, respectively with other combinations.

The superior effect of chelated fertilizers over traditional forms has been previously documented by Bozary (2012), Jahromi and Naseri (2015), and Ahmed *et al.* (2021). Chelated forms inhibit the formation of complexes with specific soil compounds, and being water-soluble, they are readily absorbed by plants when sprayed on leaves (Laishram and Baruah, 2020). Amino chelates play multiple roles in plants, including buffering pH changes, aiding in protein synthesis for plant hormones, enhancing the synthesis of metabolic products like chlorophyll, and stabilizing chlorophyll for increased photosynthesis (Aljubury *et al.*, 2001). The stable complexes formed by amino acids in amino chelates improve micronutrient absorption (Hafez *et al.*, 2014).

Foliar spraying with chelated forms of Fe, Zn, and Mn is crucial for vegetative growth. Iron is necessary for chlorophyll formation, which is essential for photosynthesis, and acts as a cofactor for redox enzymes in the electron transport chain in chloroplasts and mitochondria, playing a vital role in plant growth and development (Nikolic *et al.*, 2019; Chao and Chao, 2022; Liu *et al*., 2014). Zinc is important for auxin production, which regulates growth and development, and promotes the growth of auxinogens like IAA (Mohammed *et al*., 2018). Manganese activates enzymes involved in photosynthesis and respiration, crucial for nitrogen metabolism and absorption (Andresen *et al*., 2018).

Table 1. Effect of foliar spraying forms and time of application of Fe, Zn and Mn on shoot length of Sukkari orange during 2022 and 2023 seasons

Form of Treatment	Shoot length (cm)									
	Season 2022					Season 2023				
	Number of spraying times				Mean	Number of spraying times				Mean
	0	1	2	3		0	1	2	3	
Mineral	4.73	5.78	6.74	7.10	6.09	4.77	6.84	7.81	8.17	6.90
Chelated	4.93	7.08	8.63	11.10	7.94	4.84	8.15	9.73	12.17	8.72
Nano	4.89	6.60	7.23	9.67	7.10	4.87	7.70	8.33	10.77	7.92
Mean	4.85	6.49	7.54	9.29		4.83	7.56	8.63	10.37	
LSD at 5%	Treatment = 0.13 Number of spraying times = 0.15 Interaction = 0.25					Treatment = 0.13 Number of spraying times = 0.15 Interaction = 0.27				

Leaf area (cm^2)

Table 2 shows the effect of different forms of microelement fertilizer, the number of application and their interaction on the leaf area of Sukkari orange trees. The results indicate that all treatments improved the leaf area compared to non-sprayed trees over the three spraying times during both study seasons.

For the microelement fertilizer forms, data clearly indicated that chelated fertilizers had the most positive effect on leaf area, recording the highest values (35.45 and 36.37 cm²), followed by nano fertilizers (31.17 and 32.08cm²), and mineral fertilizers showing the lowest values (29.49and 30.41cm²) across both respectively.

Regarding the number of microelement fertilizer applications, Table 2 indicated that leaf area increased with the number of spray applications. Trees treated three times exhibited the highest leaf area (35.57 and 36.66 cm²), followed by trees sprayed twice (34.47 and 35.56 cm²). Unsprayed trees had the lowest values in this respect (24.96 and 25.37 cm²), respectively for both seasons.

The data also reveal that the interaction between the form of foliar spray and the number of applications had a notable impact on leaf area. Trees treated with chelated fertilizers and sprayed three times exhibited the largest leaf area, measuring 40.23 and 41.33 cm². This was followed by trees treated with nano fertilizers and sprayed three times, which recorded leaf areas of 34.43 and 35.50 cm². In contrast, unsprayed trees had the smallest leaf area, measuring 24.80 and 25.25 cm². Other combinations produced intermediate values across both study seasons.

These results are consistent with findings reported by El-Shazly and Dris (2004), El-Sisy (2011), Bozary (2012), Jahromi and Naseri (2015), and Ahmed *et al.* (2021).

Table 2. Effect of foliar spraying forms and time of application of Fe, Zn and Mn on leaf area of Sukkari orange during 2022 and 2023 seasons.

Form of Treatment	Leaf area (cm^2)									
	Season 2022					Season 2023				
	Number of spraying times				Mean	Number of spraying times				Mean
	0	1	2	3		0	1	2	3	
Mineral	24.80	30.20	30.93	32.03	29.49	25.25	31.23	32.03	33.13	30.41
Chelated	25.00	37.43	39.13	40.23	35.45	25.38	38.53	40.23	41.33	36.37
Nano	25.07	31.83	33.33	34.43	31.17	25.48	32.93	34.40	35.50	32.08
Mean	24.96	33.16	34.47	35.57		25.37	34.23	35.56	36.66	
LSD at 5%	Treatment = 0.81 Number of spraying times = 0.94 Interaction = 1.62					Treatment = 0.77 Number of spraying times = 0.89 Interaction = 1.55				

Chlorophyll content in the leaf (SPAD)

Table 3 presents the impact of foliar applications of iron, zinc, and manganese fertilizers (mineral, chelated, and nano forms) and application frequency (once, twice, or thrice) on Sukkari orange chlorophyll content over two seasons. The results indicated that chelated and nano fertilizers significantly increased the chlorophyll content in the leaves compared to mineral fertilizers. Specifically, chelated fertilizers recorded the highest values (86.14 and 88.17 SPAD), followed by nano fertilizers (77.97and 80.04 SPAD), while mineral fertilizers showed the lowest values (72.22 and 74.37 SPAD), respectively during both seasons.

Regarding the number of spray applications, Table 3 clearly shows that chlorophyll content in the leaves of Sukkari orange trees increased with more frequent spraying. The highest chlorophyll content in the leaf (88.00 and 89.06 SPAD) was recorded after three foliar applications, while the lowest (64.32 and 69.53 SPAD) was in unsprayed trees during both seasons, respectively. These differences were significant. Similar findings were reported by El-Shazly and Dris (2004).

Considering the interaction effect between microelement fertilizer forms and the number of spray applications, Table 3 shows that the highest chlorophyll content in the leaf were observed in trees sprayed three times with chelated forms, recording 97.80 and 98.83 SPAD, respectively, across the two seasons. In contrast, the lowest chlorophyll content in the leaf were found in unsprayed trees, recording 64.10 and 69.40 SPAD, respectively with other combinations showing intermediate values during both seasons.

Table 3. Effect of foliar spraying forms and time of application of Fe, Zn and Mn on Leaf chlorophyll content of Sukkari orange during 2022 and 2023 seasons.

Form of Treatment	Chlorophyll content in the leaf (SPAD)									
	Season 2022					Season 2023				
	Number of spraying times				mean	Number of spraying times				mean
	0	1	2	3		0	1	2	3	
Mineral	64.10	70.20	75.23	79.33	72.22	69.40	71.30	76.33	80.43	74.37
Chelated	64.37	88.67	93.73	97.80	86.14	69.57	89.47	94.80	98.83	88.17
Nano	64.50	77.70	82.80	86.87	77.97	69.63	78.80	83.83	87.90	80.04
mean	64.32	78.86	83.92	88.00		69.53	79.86	84.99	89.06	
LSD at 5%	Treatment = 0.68 Number of spraying times = 0.79 Interaction = 1.37					Treatment = 0.60 Number of spraying times = 0.69 Interaction = 1.19				

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تأثير الصورالمختلفة من الرش الورقي بالعناصر الدقيقة على النمو الخضري لأشجار البرتقال السكري

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الملخص

تم دراسة أداء أشجار البرتقال السكري تحت الصورمختلفة من الرش الورقي للعناصر الدقيقة في موسمي 2021 و 2022. هدفت الدراسة إلى معرفة تأثير الرش الورقي بمزيج من الحديد (Fe) والزنك (Zn) والمنجنيز (Mn) بأشكالها النانوية والكبريتية والمخلبية. تم رش الأوراق في ثلاثة مواعيد مختلفة: قبل الإزهار، وبعد عقد الثمار، وبعد أسبوعين من عقد الثمار. توضح النتائج أن الأسمدة المخلبية والنانوية عززت بشكل كبير النمو الخضري في البرتقال السكري مقارنة بالأسمدة المعدنية. والجدير بالذكر أن الأسمدة المخلبية أنتجت أعلى النتائج، تليها الأسمدة النانوية. في المقابل، أسفرت الأسمدة المعدنية عن أدنى خصائص النمو الخضري خلال كلا الموسمين .