Study the Effect of Organic Fertilizer, Conventional and Nano Compound Fertilizers, and Sorghum on Some Growth Traits of Bitter Orange (Citrus aurantium L.) Seedlings

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Abstract

The research problem lies in the limited availability of information concerning the combined effect of organic fertilizer, conventional compound fertilizer, nano-fertilizer, and sorghum extract on the growth and physiological performance of bitter orange (Citrus aurantium L.) seedlings under saline soil conditions. In particular, there is insufficient knowledge regarding the interaction among these factors and their role in reducing the adverse effects of salinity stress on seedling growth and development. compound, nano-fertilizers, and white sorghum intercropping on the growth of bitter orange seedlings and the interaction between fertilizer type and intercropping under saline or low-fertility soil conditions. The experiment included adding of organic fertilizer (buffalo manure) at three levels: 0, 1.413 kg plant^{-1}, and 1.413 kg organic fertilizer + 5 g nano-fertilizer per plant. The organic fertilizer was applied in a single dose.The chemical fertilizer NPK (20-20-20) was applied at three levels: 0, 28.26 g plant^{-1}, and 28.26 g compound fertilizer + 5 g nano-fertilizer per plant, which was applied in three times: the first after transplanting, the second 45 days after the first, and the third 45 days after the second, while The third factor was white sorghum intercropping at two levels (A1: sorghum cultivation, A2: without cultivation. A factorial experiment was conducted according to a Randomized Complete Block Design (RCBD) with three replications. Means were compared using Duncan's Multiple Range Test at a 0.05 probability level. The results showed that the application of organic fertilizer, conventional compound fertilizer, nano-fertilizer, and sorghum extract significantly improved the vegetative growth and physiological characteristics of bitter orange seedlings under saline conditions. The best treatment recorded the highest values for plant height, stem diameter, number of leaves, leaf area, and chlorophyll content, with percentage increases compared to the control treatment reaching significant levels. In addition, significant interaction effects among the studied factors were observed, indicating that the combined application of these treatments was more effective in reducing the adverse effects of salinity stress and enhancing seedling growth than the individual applications.

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Keywords : bitter orange, organic fertilizer, compound fertilizer, nano-fertilizer, sorghum intercropping.

Introduction

The introduction referred to the study factors in a general manner, but it did not adequately clarify the scientific basis for the interaction among organic fertilizer, conventional compound fertilizer, nano-fertilizer, and sorghum extract, nor did it explain the actual reason for selecting these factors together in the same experiment. Therefore, the introduction should include a clear justification for the expected complementary or synergistic effects of these treatments in improving nutrient availability, enhancing salinity tolerance, and promoting the growth and physiological characteristics of bitter orange (Citrus aurantium L.) seedlings under saline conditions. aurantium L.) is considered an important citrus species. It is widely used as a rootstock for grafting many citrus cultivars due to its high tolerance to adverse environmental conditions. In addition, it has significant economic and nutritional value in Iraq. bitter orange is widely cultivated in Diyala Governorate its trees are relatively tolerant to saline soils and are capable of maintaining satisfactory growth and development under salinity conditions. They are also adapted to high temperature environments, while citrus fruits in general are recognized as a rich source of vitamins [1,2,3]

Previous studies have highlighted the important role of organic fertilizers of improving soil fertility and plant performance. Organic amendments enhance soil physical properties, including soil structure, porosity, bulk density, and soil aeration. They also improve soil chemical characteristics such as soil pH, electrical conductivity (EC), cation exchange capacity (CEC), and the carbon to nitrogen ratio (C/N). Consequently, organic fertilization contributes to improving soil fertility, increasing nutrient availability, and enriching soil organic matter, which ultimately enhances plant growth and productivity [4][5]

Compound fertilizers (NPK) are considered an important and rapid source of essential macronutrients for plant growth. Their application plays a key role in increasing agricultural productivity and improving farmers' livelihood through enhanced crop yields [5]. One of the major constraints in agricultural soils is low fertility; therefore, nutrient supplementation through compound fertilizers (NPK) represents an effective strategy to overcome nutrient deficiencies, as these fertilizers supply readily available nutrients that enhance soil fertility [7]

Recently, increasing attention has been directed toward the application of nano-fertilizers, which are nutrient formulations engineered at the nanoscale (1–100 nm). These fertilizers possess unique physicochemical properties, including a large surface area that enhances nutrient use efficiency and reduces nutrient losses in the soil. Several studies reported that nano-fertilizer application significantly improved vegetative growth parameters such as plant height, leaf number, and dry matter accumulation, due to their ability to release nutrients gradually in a controlled manner [8,9]

White Sorghum (*Sorghum bicolor* L. *Moench*) is an important crop globally in Iraq. It ranks as the fifth most important cereal crop after wheat, barley, rice, and maize. Sorghum has the ability to grow under diverse environmental conditions and serves as a staple food for large populations in Asia and Africa [10]

Furthermore, sorghum is well known for its high tolerance to salinity and drought stress, High soil salinity, low soil fertility, and reduced nutrient uptake efficiency are among the major constraints affecting agricultural soils. These factors negatively influence the growth of bitter orange seedlings, which are considered one of the most important citrus species. Such challenges necessitate the development of effective strategies to enhance plant growth. Therefore, this study aims to:

Evaluate the effect of organic fertilizer, conventional compound fertilizer, and nano-fertilizer on the vegetative growth of bitter orange seedlings.

Assess the impact of these treatments on bitter orange seedling growth and the performance of sorghum as an associated crop under intercropping conditions.

Evaluate the interaction between fertilizer types and sorghum under saline soil conditions.

Determine the most effective treatment for improving bitter orange seedling growth and soil physicochemical properties. properties.

The significance of this study lies in addressing a clear research gap represented by the limited number of studies that combine these agricultural inputs within a single production system, despite their importance in improving soil quality and supporting the growth of sour orange seedlings. Therefore, this research contributes to promoting sustainable agricultural practices that conserve natural resources, enhance crop productivity and quality, and minimize negative environmental impacts.

Materials and Methods

The experiment was conducted in a field belonging to the College of Agriculture, University of Diyala during the spring growing season of 2025, on bitter orange seedlings (Citrus aurantium L.), a local cultivar grafted onto Cleopatra mandarin rootstock. The study aimed to investigate the effect of organic fertilizer, conventional compound fertilizer, chelated nano NPK fertilizer (20:20:20), and white sorghum intercropping on the growth of bitter orange seedlings. The nano-fertilizer used in this study was a chelated nano NPK fertilizer (20:20:20) produced by Khazra Company (UAE). The fertilizer contains nitrogen, phosphorus, and potassium in nano form and is completely water-soluble. The nano-fertilizer was dissolved in water and applied manually to the soil around each seedling according to the recommended rate during the experimental period. and white sorghum intercropping on the growth of bitter orange seedlings. A total of 54 seedlings were planted on 16/4/2025, ensuring uniformity in size and vigor as much as possible.

The soil was plowed using a rotary plow to a depth of 70–75 cm and a width of 60 cm. Buffalo manure (1.413 kg) was added into each pit and mixed with soil using the rotary plow. Seedlings were planted at a

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spacing of 2 m among plants under a drip irrigation system.

The experiment consisted of three replicates, with 18 seedlings per replicate. Some physical and chemical properties of the field soil were analyzed before conducting the experiment. Soil samples were collected from a depth The suitability of conducting nutrient analysis at a soil depth of 0–30 cm should be justified according to the rooting depth of the planted bitter orange seedlings. Since nutrient uptake is closely related to root distribution, it is necessary to clarify whether this depth adequately represents the active root zone of the seedlings under the experimental conditions.as shown in Table (1).

Experimental Design

The experiment was conducted as a factorial experiment in a Randomized Complete Block Design (RCBD) The study included three factors: The first factor: organic fertilizer (buffalo manure) at three levels (O1, O2, O3). The second: compound chemical fertilizer NPK (20–20–20) at three levels (C1, C2, C3).

The third factor: white sorghum intercropping

at two levels (A1, A2). were randomly distributed within each block. Experimental Factors and Their Levels

The experiment included three factors:

First Factor: Organic Fertilizer (Buffalo Manure)

Three levels were applied:

0control treatment

1.413kg organic fertilizer per plant

1.413kg organic fertilizer The basis for selecting the 5 g nano-fertilizer level was not clearly explained. Therefore, it is necessary to justify the chosen concentration by referring to previous studies, manufacturer recommendations, or preliminary experimental results demonstrating the suitability and effectiveness of this level for bitter orange seedlings under saline conditions. loaded onto the organic fertilizer and applied to the plant

These treatments were denoted as (O0, O1, O2), respectively. The fertilizer was applied in a single dose after planting. The organic fertilizer was analyzed to determine its composition in the laboratory (Table 2.)

Second Factor: Compound NPK Fertilizer

Three levels were applied:

0control treatment

28.26g NPK per plant

28.26g NPK + 5 g nano-fertilizer per plant (nano-fertilizer loaded onto the compound fertilizer

These treatments were denoted as (Co, C1, C2), respectively. Fertilizer application was carried out in three split doses: the first at planting, the second 45 days after the first, and the third 45 days after the second.

Third Factor: White Sorghum

Two levels were included:

With sorghum cultivation (A1)

Without sorghum cultivation (A2)

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During this period, the moisture level was maintained at approximately 40%, and the material was turned periodically to ensure proper aeration and uniform decomposition.

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Table (1) some chemical and physical properties of the soil of the study before planting

Unit	Value	Properties	
ds-1	9.7	EC Conductivity (1:1)	
	7.7	pH (1:1)	
g kg-1	1.26	Organic matter	
Cmolc kg-1	23.50	Positive ion exchange capacity CEC	
Mg m-3	1.40	Bulk density	
Mmol l-1	6.12	Calcium Ca+	Soluble ions
	5	Magnesium Mg+	
	6.54	Sodium Na+	
	2.36	Potassium K+	
	11.68	Chloride Cl^{-1}	
	1.32	Sulfate SO_4^{-1}	
	7	Bicarbonate HCo_3^{-1}	
	Nill	Carbonate CO_3^{-2}	
mg kg^{-1} soil	6.54	Nitrogen	Elements available
	9.81	Phosphorus	
	117.3	Potassium	
%	24	Clay	Sand Clay Loam
	20	Alluvial	
	56	Sand	

Soil samples were analyzed at the College of Agriculture, University of Diyala, in the Soil Fertility Laboratory, Department of Soil Sciences.

Preparation of Organic Fertilizer

Animal manure (buffalo waste) was collected from a local farm and prepared by placing it in a pit with dimensions of 2.5 m length × 2.5 m width × 1.0 m height in the form of layers. The

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material was then moistened with water to reach approximately 40% moisture content and covered with plastic sheets for a period of three months to ensure complete decomposition and to eliminate weed seeds and impurities The moisture level was maintained at 40% throughout the decomposition period. The material was turned periodically to ensure proper aeration and uniform decomposition

Table 2 shows some of the chemical properties of organic fertilizer (buffalo manure).

Properties		Value	Unit
Desi Samnazm^{-1}	22.8	EC Conductivity (1:1)	
	6.78	pH (1:1)	
g kg-1	23.4	Organic matter	
	16.1	C\N	
Mica Gram. 1 kg^{-1}	0.49	Bulk density	
	17.6	Calcium Ca^+	
	10.2	Magnesium Mg^+	
Millimol L^{-1}	661.64	Sodium Na^+	Soluble ions
	779.79	Potassium K^+	
	4.60	Chloride Cl^{-1}	
	0.813	Sulfate SO_4^{-1}	
	5	Bicarbonate HCo_3^{-1}	

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	Nill	Carbonate CO_3^{-2}	
	4.57	Nitrogen	Elements available
%	2.76	Phosphorus	
	3.81	Potassium	

Study Indicators

Initial measurements were taken at the beginning of April, and final measurements were recorded at the beginning of December for both leaf and soil samples. Measurements included vegetative growth and chemical characteristics as follows:

Studied Traits

1-Increasing in Plant Height (cm)

Plant height was measured using a metric measuring tape from the soil surface to the tip of the plant. Initial readings were recorded before applying treatments, and final readings were taken at the end of the experiment. The difference between the two readings represents the increase in plant height.

2-Increasing in Main Stem Diameter (mm)

Stem diameter was measured at 5 cm above the soil surface using a digital caliper. Initial measurements were taken before treatment application, and final measurements were recorded at the end of the experiment. The difference represents the increase in stem diameter.

3-Increasing in Number of Leaves (leaf branch^{-1})

The number of leaves was counted on two tagged branches per seedling before treatment application and at the end of the experiment. The difference represents the increase in the number of leaves.

4-Leaf Area (cm^2)

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Leaf area was estimated by selecting the fourth and fifth leaves from the top of one-year-old shoots. Three leaves per plant were randomly sampled from different positions at the end of the experiment. Leaf area was calculated using the following equation (Al-Qaysi, 1999):

S=0.785*L*W

Where :

S = Leaf area (cm²)

L = Leaf length (cm)

W = Leaf width (cm)

= 0.785Constant for elliptical leaves

5- Total Leaf Chlorophyll Content(

Leaf chlorophyll content of sour orange plants was determined using a SPAD-50 chlorophyll meter. Measurements were taken from 54 plants per experimental unit, and the mean value was calculated based on three leaves randomly selected from the mid-canopy of each plant. Readings were obtained by placing a portion of the leaf lamina between the meter clamps and applying slight pressure, after which the value was displayed directly on the device screen

Results and Discussion

1-Plant Height:

Table (3) shows the effect of adding organic fertilizer, conventional , nano compound chemical fertilizer (NPK), and sorghum intercropping on the plant height of bitter orange seedlings. The results of the statistical analysis indicated that the effect of intercropping (A) was significant. The treatment without sorghum intercropping (A2) had a significant effect on the height of bitter orange plants after the third fertilizer application, recording a value of 149.77 cm compared to the sorghum intercropping treatment (A1), which recorded 133.51 cm, with an increase of 12.17 cm.

As for the effect of organic fertilizer (B) and compound chemical fertilizer (NPK) (C), there were no significant differences among the treatments.

Regarding the interaction between intercropping and organic fertilizer (AB), the treatment without sorghum intercropping combined with organic fertilizer addition (A2B2) showed a significant superiority, recording the highest value of 156.55 cm. The lowest value was observed in the treatment with sorghum intercropping combined with organic + nano fertilizer (A1B3), which recorded 131.33 cm, with an increase of 19.20 cm.

For the interaction between intercropping and compound chemical fertilizer (AC), the treatment without sorghum intercropping with the control under NPK application (A2C1) showed significant superiority, recording the highest value of 159.66 cm. The lowest value was observed in the treatment with sorghum intercropping and control under NPK application (A1C1), which recorded 122.11 cm, with an increase of 30.75 cm.

As for the interaction between organic fertilizer and compound chemical fertilizer (BC), the control treatment with organic fertilizer combined with conventional + nano NPK fertilizer (B1C3) showed significant superiority, recording the highest value of 166.00 cm. The lowest value was observed in the treatment with organic + nano fertilizer combined with conventional + nano NPK fertilizer (B3C3), which recorded 118.00 cm, with an increase of 40.67 cm.

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Regarding the triple interaction (ABC), the treatment without sorghum intercropping with the control organic fertilizer combined with conventional + nano NPK fertilizer (A2B1C3) showed significant superiority, recording the highest value of 172.33 cm. The lowest value was observed in the treatment without sorghum intercropping with organic + nano fertilizer combined with conventional + nano NPK fertilizer (A2B3C3), which recorded 111.00 cm, with an increase of 55.25 cm.

Table (3): Effect of organic fertilizer, conventional and nano compound chemical fertilizer (NPK), and intercropping (sorghum) on the height (cm) of sour orange plants after the third fertilizer application

White Sorghum (A)	(B)Fertilizer Organic	C) (Compound fertilizer NPK			A*B	Mean A	Mean B
		C1) Control(	C2) Convenlional Fertilizer NPK	Convenlional Fertilizer NPK+ Nano (C3)			
With Sorghum (A1)	Control B1	111.67 e	129.00cde	159.67 abc	133.44 c		
	)B)Fertilizer Organic	128.33cde	130.00 b-e	149.00 a-d	135.77 bc		
	Organic+ Nano(B3)	126.33 cde	142.67 a-e	125.00 cde	131.33 c		
Without Sorghum (A2)	B1 Control	167.33 a	121.33 De	172.33 A	153.66 ab		
	)B)Fertilizer Organic	147.67 a-d	166.67 A	155.33 a-d	156.55 a		
	Organic+ Nano(B3 (	164.00 ab	142.33 a-e	111.00 E	139.11abc		
White Sorghum A)(	With Sorghum (A1(	122.11 c	133.88 Bc	144.55 ab		133.51 B	
	Without Sorghum (A2(	159.66 a	143.44 Ab	146.22 ab		149.77 A	
)B)Fertilizer Organic	B1 Control	139.50 bcd	125.17 Cd	166.00 A			143.55 A
	)B)Fertilizer Organic	138.00bcd	148.33abc	152.17 ab			146.16 A
	Organic+ Nano(B3 (	145.17 abc	142.50 Bc	118.00 D			135.22 A

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C Mean NPK	140.88 A	138.66 A	145.38 A			

2. Stem Diameter:

Table (4) shows the effect of adding organic fertilizer, conventional and nano compound chemical fertilizer (NPK), and sorghum intercropping on the stem diameter of bitter orange seedlings. The results of the statistical analysis indicated that the effect of intercropping (A) was significant, where the sorghum intercropping treatment (A1) significantly increased stem diameter (mm) of bitter orange plants after the third fertilizer application, recording a value of 12.45 mm compared with the non-intercropping treatment (A2), which recorded 11.46 mm, with an increase of 8.63%.

Regarding the effect of organic fertilizer (B), the control treatment (B1) showed a significant superiority, recording a value of 12.56 mm compared with organic fertilizer treatment (B2) and organic + nano fertilizer treatment (B3), which recorded 12.35 mm and 10.96 mm, respectively, with increases of 1.70 mm and 14.59%, respectively.

As for the effect of compound chemical fertilizer (NPK) (C), there were no significant differences among treatments.

Regarding the interaction between intercropping and organic fertilizer (AB), the sorghum intercropping treatment combined with the control organic fertilizer (A1B1) showed significant superiority, recording the highest value of 13.06 mm. The lowest value was observed in the non-intercropping treatment combined with organic + nano fertilizer (A2B3), which recorded 10.34 mm, with an increase of 26.30%.

For the interaction between intercropping and compound chemical fertilizer (AC), the sorghum intercropping treatment combined with conventional + nano NPK fertilizer (A1C3) showed significant superiority, recording the highest value of 12.85 mm. The lowest value was observed in the non-intercropping treatment combined with conventional NPK fertilizer (A2C2), which recorded 11.06 mm, with an increase of 16.18%.

Regarding the interaction between organic fertilizer and compound chemical fertilizer (BC), the control organic fertilizer combined with conventional + nano NPK fertilizer (B1C3) showed significant superiority, recording the highest value of 13.24 mm. The lowest value was observed in the organic + nano fertilizer combined with conventional NPK fertilizer (B3C2), which recorded 10.67 mm, with an increase of 24.08%.

As for the triple interaction (ABC), the sorghum intercropping treatment combined with control organic fertilizer and conventional NPK fertilizer (A1B1C2) showed significant superiority, recording the highest value of 13.58 mm. The lowest value was observed in the non-intercropping treatment combined with organic + nano fertilizer and conventional + nano NPK fertilizer (A2B3C3), which recorded 8.99 mm, with an increase of 51.05%.

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Table (4): Effect of organic fertilizer, conventional and nano compound chemical fertilizer (NPK), and intercropping (sorghum) on stem diameter (mm) of sour orange plants after the third fertilizer application

(A) White Sorghum	)B)Fertilizer Organic	C)) Compound fertilizer NPK			A*B	Mean A	Mean B
		C1) Control)	C2) Convenlional Fertilizer NPK	Convenlional Fertilizer NPK+ Nano (C3)			
With Sorghum (A1(	B1 Control	12.35a-d	13.58a	13.06ab	13.06a		
	)B)Fertilizer Organic	13.23ab	12.12a-d	12.83ab	12.72ab		
	Organic+ Nano(B3 (	11.99a-d	10.29cde	12.45abc	11.58b		
Without Sorghum (A2(	B1 Control	12.87ab	10.11de	13.22ab	12.06ab		
	(B) Fertilizer Organic	12.01a-d	12.03a-d	11.87a-d	11.97ab		
	Organic+ Nano(B3 (	10.99b-e	11.05b-e	8.99e	10.34c		
White Sorghum A)(	With Sorghum (A1(	12.52ab	11.99abc	12.85a		12.45A	
	Without Sorghum (A2(	11.96abc	11.06c	11.36bc		11.46B	
)B)Fertilizer Organic	B1 Control	12.61ab	11.84abc	13.24a			12.56A
	)B)Fertilizer Organic	12.62ab	12.07abc	12.35ab			12.35A
	Organic+ Nano(B3 (	11.49bc	10.67c	10.72c			10.96B
C Mean NPK		12.24A	11.53A	12.10A			

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3. Number of Leaves:

Table (5) shows the effect of adding organic fertilizer, conventional and nano compound chemical fertilizer (NPK), and sorghum intercropping on the number of leaves of bitter orange seedlings. The statistical analysis results indicated that the effect of intercropping (A) was not significant on the number of leaves (leaf branch^{-1}) in bitter orange plants after the third fertilizer application.

Regarding the effect of organic fertilizer (B), the control treatment (B1) showed a significant superiority, recording a value of 113.00 leaves per branch compared with organic fertilizer treatment (B2) and organic + nano fertilizer treatment (B3), which recorded 99.77 and 87.72 leaves per branch, respectively, with increases of 13.26 and 28.81 leaves per branch, respectively

As for the effect of compound chemical fertilizer (NPK) (C), the control treatment (C1) showed significant superiority, recording 115.94 leaves per branch^{-1} compared with conventional NPK (C2) and NPK + nano (C3), which recorded 85.05 and 99.50 leaves per branch^{-1}, respectively, with increases of 36.31 and 16.52 leaves per branch^{-1}, respectively

Regarding the interaction between intercropping and organic fertilizer (AB), the non-intercropping treatment combined with the control organic fertilizer (A2B1) showed significant superiority, recording the highest value of 124.56 leaves per branch^{-1}. The lowest value was observed in the non-intercropping treatment combined with organic + nano fertilizer (A2B3), which recorded 82.89 leaves per branch^{-1}, with an increase of 50.27 leaves per branch^{-1}.

For the interaction between intercropping and compound chemical fertilizer (AC), the non-intercropping treatment combined with control NPK (A2C1) showed significant superiority, recording the highest value of 120.89 leaves per branch^{-1}. The lowest value was observed in the intercropping treatment combined with conventional NPK (A1C2), which recorded 84.11 leaves per branch^{-1}, with an increase of 43.72 leaves per branch^{-1}.

Regarding the interaction between organic fertilizer and compound chemical fertilizer (BC), the control organic fertilizer combined with control NPK (B1C1) showed significant superiority, recording the highest value of 130.67 leaves per branch^{-1}. The lowest value was observed in the organic + nano fertilizer combined with NPK + nano fertilizer (B3C3), which recorded 82.00 leaves per branch^{-1}, with an increase of 59.35 leaves per branch^{-1}.

As for the triple interaction (ABC), the non-intercropping treatment combined with control organic fertilizer and control NPK (A2B1C1) showed significant superiority, recording the highest value of 163.33 leaves per branch^{-1}. The lowest value was observed in the non-intercropping treatment combined with organic + nano fertilizer and conventional NPK (A2B3C2), which recorded 68.00 leaves per branch^{-1}, with an increase of 140.19 leaves per branch^{-1}.

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Table (5): Effect of organic fertilizer, conventional and nano compound chemical fertilizer (NPK), and intercropping (sorghum) on the number of leaves (leaf branch⁻¹) of sour orange plants after the third fertilizer application.

(A) White Sorghum	)(B Fertilizer Organic	C)) Compound fertilizer NPK C1) Control)	C2) Convenlional Fertilizer NPK	Convenlional Fertilizer NPK+ Nano (C3)	A*B	Mean A	Mean B
With Sorghum (A1(	Control B1	98.00cd	81.67cd	124.67abc	101.44ab		
	(B) Fertilizer Organic	145.67ab	74.33d	102.33bcd	107.44ab		
	Organic+ Nano(B3 (	89.33cd	96.33cd	92.00cd	92.56b		
Without Sorghum (A2(	B1 Control	163.33a	97.33cd	113.00bcd	124.56a		
	(B) Fertilizer Organic	90.67cd	92.67cd	93.00cd	92.11b		
	Organic+ Nano(B3 (	108.67bcd	68.00d	72.00d	82.89b		
White Sorghum A)(	With Sorghum (A1(	111.00ab	84.11c	106.33abc		100.48A	
	Without Sorghum (A2(	120.89a	86.00bc	92.67bc		99.85A	
(B) Fertilizer Organic	B1 Control	130.67a	89.50bc	118.83ab			113.00A
	(B) Fertilizer Organic	118.17ab	83.50c	97.67bc			99.77AB
	Organic+ Nano(B3 (	99.00bc	82.17c	82.00c			87.72B
C Mean NPK		115.94A	85.05B	99.50AB			

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4-Leaf Area:

Table (6) shows the effect of adding organic fertilizer, conventional and nano compound chemical fertilizer (NPK), and sorghum intercropping on the leaf area of bitter orange seedlings. The statistical analysis results indicated that the effects of intercropping (A), organic fertilizer (B), and compound chemical fertilizer (NPK) (C) were not significant on leaf area (cm²) of sour orange plants after the third fertilizer application.

Regarding the interaction between intercropping and organic fertilizer (AB), the sorghum intercropping treatment combined with organic fertilizer (A1B2) showed significant superiority, recording the highest value of 258.56 cm². The lowest value was observed in the non-intercropping treatment combined with organic + nano fertilizer (A2B3), which recorded 230.14 cm², with an increase of 12.34 cm².

As for the interaction between intercropping and compound chemical fertilizer (AC), there were no significant differences among treatments.

Regarding the interaction between organic fertilizer and compound chemical fertilizer (BC), the organic + nano fertilizer combined with control NPK (B3C1) showed significant superiority, recording the highest value of 265.20 cm². The lowest value was observed in the control organic fertilizer combined with control NPK (B1C1), which recorded 215.41 cm², with an increase of 23.11 cm².

As for the triple interaction (ABC), the sorghum intercropping treatment combined with organic + nano fertilizer and control NPK (A1B3C1) showed significant superiority, recording the highest value of 279.24 cm². The lowest value was observed in the non-intercropping treatment combined with organic + nano fertilizer and NPK + nano fertilizer (A2B3C3), which recorded 195.55 cm², with an increase of 42.79 cm².

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Table (6): Effect of organic fertilizer, conventional and nano compound chemical fertilizer (NPK), and intercropping (sorghum) on leaf area (cm²) of sour orange plants after the third fertilizer application.

White SorghumA)(	(B) Fertilizer Organic	C)) Compound fertilizer NPK			A*B	Mean A	Mean B
		C1) Control)	C2) Convenlional Fertilizer NPK	Convenlional Fertilizer NPK+ Nano (C3)			
With Sorghum (A1(	Control B1	199.48ef	255.71a-d	245.78a-d	233.66ab		
	(B) Fertilizer Organic	273.21abc	256.10a-d	246.38a-d	258.56a		
	Organic+ Nano(B3 (	279.24a	211.05def	260.59abc	250.29ab		
Without Sorghum (A2(	B1 Control	231.34b-f	262.38abc	275.76abc	256.49a		
	(B) Fertilizer Organic	240.16a-e	227.31c-f	259.96abc	242.48ab		
	Organic+ Nano(B3 (	251.16a-d	243.71a-e	195.55f	230.14b		
White Sorghum A)(	With Sorghum (A1(	250.64a	240.95a	250.92a		247.50A	
	Without Sorghum (A2(	240.89a	244.47a	243.76a		243.03A	
(B) Fertilizer Organic	B1 Control	215.64c	259.05a	260.77a			245.07A
	(B) Fertilizer Organic	256.69ab	241.70abc	253.17ab			250.51A
	Organic+ Nano(B3 (	265.20a	227.38bc	228.07bc			240.21A
C Mean NPK		245.20A	242.70A	247.33A			

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5-Leaf Chlorophyll Content:

The statistical analysis results of Table (7) indicated that the effect of intercropping (sorghum) (A) showed a significant difference, where the non-intercropping treatment (A2) recorded a higher chlorophyll content of 55.76 mg 100 g^{-1} fresh weight compared to the intercropping treatment (A1), which recorded 46.14 mg 100 g^{-1} fresh weight, with an increase of 20.84%.

Regarding the effect of organic fertilizer (B), the organic + nano fertilizer treatment (B3) showed significant superiority, recording 59.68 mg 100 g^{-1} fresh weight compared to the control (B1) and organic fertilizer (B2), which recorded 52.77 and 45.40 mg 100 g^{-1} fresh weight, respectively, with increases of 13.09% and 31.45%, respectively.

As for the effect of compound chemical fertilizer (NPK) (C), there were no significant differences among treatments.

Regarding the interaction between intercropping and organic fertilizer (AB), the non-intercropping treatment combined with the control organic fertilizer (A2B1) showed significant superiority, recording the highest value of 59.97 mg 100 g^{-1} fresh weight. The lowest value was observed in the

intercropping treatment combined with organic fertilizer (A1B2), which recorded 43.04 mg 100 g^{-1} fresh weight, with an increase of 39.33%.

For the interaction between intercropping and compound chemical fertilizer (AC), the non-intercropping treatment combined with control NPK (A2C1) showed significant superiority, recording the highest value of 58.13 mg 100 g^{-1} fresh weight. The lowest value was observed in the intercropping treatment combined with control NPK (A1C1), which recorded 41.69 mg 100 g^{-1} fresh weight, with an increase of 39.43%.

Regarding the interaction between organic fertilizer and compound chemical fertilizer (BC), the organic + nano fertilizer combined with NPK + nano fertilizer (B3C3) showed significant superiority, recording the highest value of 62.09 mg 100 g^{-1} fresh weight. The lowest value was observed in the organic fertilizer combined with conventional NPK (B2C2), which recorded 36.54 mg 100 g^{-1} fresh weight, with an increase of 69.92%.

As for the triple interaction (ABC), the non-intercropping treatment combined with control organic fertilizer and conventional NPK (A2B1C2) showed significant superiority, recording the highest value of 65.94 mg 100 g^{-1} fresh weight. The lowest value was observed in the intercropping treatment combined with control organic fertilizer and control NPK (A1B1C1), which recorded 35.46 mg 100 g^{-1} fresh weight, with an increase of 88.45%.

Table (7): Effect of organic fertilizer, conventional and nano compound chemical fertilizer (NPK), and intercropping (sorghum) on chlorophyll content (mg 100 g^{-1} fresh weight) in the leaves of sour orange plants after the third fertilizer application.

(A) White Sorghum	B)(Fertilizer Organic	C)) Compound fertilizer NPK			A*B	Mean A	Mean B
		C1) Control)	C2) Convenlional Fertilizer NPK	Convenlional Fertilizer NPK+ Nano (C3)			
With Sorghum (A1(	Control B1	35.46f	53.42bcd	47.81c-f	45.56bc		
	(B) Fertilizer Organic	48.58cde	36.67ef	43.88def	43.04c		
	Organic+ Nano(B3 (	41.04def	47.48c-f	60.89ab	49.80b		
Without Sorghum (A2(	B1 Control	61.99ab	65.94a	52.00bcd	59.97a		
	(B) Fertilizer Organic	59.09abc	36.40ef	47.81c-f	47.76bc		
	Organic+ Nano(B3 (	53.32bcd	62.04ab	63.30ab	59.55a		
White Sorghum A)(	With Sorghum (A1(	41.69d	45.86cd	50.86bc		46.14B	
	Without Sorghum (A2(	58.13a	54.79ab	54.37ab		55.76A	
(B) Fertilizer Organic	B1 Control	48.72cd	59.68ab	49.90cd			52.77A
	(B) Fertilizer Organic	53.83bcd	36.54e	45.84d			45.40B
	Organic+ Nano(B3 (	47.18cd	54.76abc	62.09a			54.68A
C Mean NPK		49.91A	50.32A	52.61A			

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-Discussion of the Studied Traits in Sour Orange Seedlings:

This result agrees with the findings of (11). The superiority of the chemical and nano fertilizer treatments may be attributed to the properties of these fertilizers and their ability to provide essential nutrients required by the plant during different growth stages. The addition of fertilizers to the soil affects vegetative growth characteristics, including plant height, stem diameter, number of leaves, and leaf area. These fertilizers increase the availability of nutrients in the soil, improve nutrient uptake efficiency, and stimulate physiological processes within the plant, which is reflected in improved plant growth (12). Conventional chemical compound fertilizer (NPK) affects the concentrations of nutrients in the plant, increases chlorophyll content and mineral analysis in plant tissues, and increases the concentrations of elements (nitrogen, phosphorus, potassium, calcium, and magnesium), which leads to an increase in plant yield (13).

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