Journal homepage
www.ajas.uoanbar.edu.iq
**Anbar Journal of Agricultural Sciences**
(University of Anbar – College of Agriculture)

# EFFECT OF MICRONUTRIENT NANOPARTICLES INJECTION AND SEAWEED EXTRACT APPLICATION ON SOME VEGETATIVE, CHEMICAL CHARACTERISTICS, AND YIELD OF APPLE TREES CV. IBRAHIMI

**M. H. Hussien *** **R. M. Hamad**

**Department of Horticulture, College of Agriculture, University of Anbar, Iraq**

***Correspondence to:** Mohammed Hamad Hussien, Department of Horticulture, College of Agriculture, University of Anbar, Iraq.
**Email:** mih23g5007@uoanbar.edu.iq

**Article info**

**Received:** 2024-11-18
**Accepted:** 2025-01-28
**Published:** 2025-06-30

**DOI-Crossref:**
10.32649/ajas.2025.186769

**Cite as:**
Hussien, M. H., and Hamad, R. M. (2025). Effect of micronutrient nanoparticles injection and seaweed extract application on some vegetative, chemical characteristics, and yield of apple trees cv. ibrahimi. Anbar Journal of Agricultural Sciences, 23(1): 755-769.



**Abstract**

The experiment was conducted in the village of Al-Bu-dhiyab, west of Ramadi during 16\3\2024 to 1\7\2024 spring season on 5-year-old Ibrahimi apple trees, to study the effects of injection micro-Nano elements and soil application of seaweed extract on vegetative growth, chemical properties, and yield. The experiment included three levels of injection: (0 - injection with distilled water only, B10+Fe20, and B20+Fe40 (mg $L^{-1}$)) and the addition of seaweed extract at four concentrations: (0 soil application of pure water from distillation, 3, 6, and 9 ml. $L^{-1}$). Treatments were applied in three batches on March 16, with a 20-day interval between each treatment. The following characteristics were studied: leaf area, total chlorophyll content, fruit set, fruit weight, fruit size, total yield, total sugar, total acidity, and pectin percentage in fruits. The findings indicated that the injectable therapy (B20+ (Fe40 mg $L^{-1}$) resulted in a substantial enhancement of all examined features. Likewise, the incorporation of seaweed extract (9 ml $L^{-1}$) resulted in an extensive improvement for examined attributes. The interaction between the study components revealed that the injectable therapy at the concentration of B20+(Fe40) and the addition of seaweed extracted with a level for 9 ml $L^{-1}$ performed in all evaluated features.

**Keywords:** Apple, Injection, Nanotechnology, Seaweed extract.

# تأثير الحقن بالعناصر الصغرى النانوية وإضافة مستخلص الطحالب البحرية في بعض صفات النمو الخضري والكيميائي والحاصل لأشجار التفاح صنف ابراهيمي

محمد حماد حسين * رسمي محمد حمد

قسم البستنة وهندسة الحدائق، كلية الزراعة، جامعة الانبار

*المراسلة الى: محمد حماد حسين، قسم البستنة وهندسة الحدائق، كلية الزراعة، جامعة الانبار، العراق.

البريد الالكتروني: mih23g5007@uoanbar.edu.iq

**الخلاصة**

نفذت التجربة في قرية البوذياب – شمال غرب مدينة الرمادي في الموسم الربيعي من 2024/3/16 ولغاية 2024/7/1 على أشجار التفاح صنف ابراهيمي بعمر 5 سنوات، لدراسة تأثير الحقن بالعناصر النانوية الصغرى واضافة مستخلص الطحالب البحرية على صفات النمو الخضري والكيميائي والحاصل، تضمنت التجربة ثلاث مستويات من الحقن (0 الحقن بالماء المقطر فقط، B10+Fe20 و(Fe40)+B20 ملغم لتر $^{-1}$ واضافة مستخلص الطحالب البحرية بأربع مستويات (0 اضافة الماء المقطر فقط، 3، 6 و9 مل لتر $^{-1}$) تمت المعاملة على ثلاث دفعات في السادس عشر اذار وبين معاملة وأخرى 20 يوم. درست الصفات التالية؛ مساحة الورقة، محتوى الأوراق من الكلوروفيل الكلي، نسبة العقد، وزن الثمرة، حجم الثمرة، الحاصل الكلي، نسبة السكريات الكلية، نسبة الحموضة الكلية ونسبة البكتين في الثمار.

اظهرت النتائج ان مستوى الحقن (Fe40)+B20 ملغم لتر $^{-1}$ أدى الى زيادة معنوية في جميع الصفات المدروسة. اما بالنسبة لعامل اضافة مستخلص الطحالب البحرية (9 مل لتر $^{-1}$) ادى الى زيادة معنوية في جميع الصفات المدروسة ايضاً. اما مستويات التداخل بين عاملي الدراسة فان عامل الحقن بالتركيز (Fe40)+B20 واضافة مستخلص الطحالب البحرية بالتركيز (9 مل لتر $^{-1}$) قد تفوق في جميع الصفات المدروسة.

**كلمات مفتاحية:** التفاح، الحقن، تقنية النانو، مستخلص الطحالب البحرية.

## Introduction

An apple fruits (*Malus domestica* Borkh) usually a member of the Rosaceae group, which is thought that its native habitat is the temperate region of Southeast Asia, it expanded across Europe as well as elsewhere (11). Apple fruits are among the richest in pectin, which helps lower cholesterol and prevents its accumulation in human blood vessels, thus reducing blood pressure and alleviating symptoms of joint diseases that affect the elderly (33).

Although the plant receives enough nutrients and soil amendments, there are significant losses in fertilizer application, particularly in extensive agricultural regions, leading researchers to explore other techniques of fertilizer delivery (34). The efficacy of any method employed for injecting tree trunks must satisfy four criteria Moreover, trunk injection for fertilizing trees offers distinct benefits, including the absence of environmental pollution, enhanced efficiency, and no limitations on tree height, facilitating quicker and more uniform fertilizer distribution throughout the tree via transpiration (32). Nanotechnology, or nanoscience, concentrates on the examination of material processing at the atomic scale (10–9 nano meters), since nanomaterials display features that diverge from those of their conventional dimensions reaching 100 nanometers (15).

Nanotechnology, a pioneering force in contemporary agriculture, is expected to emerge as a significant catalyst in the near future by advancing applications designed to improve fertilizer efficacy and address nutritional shortages. Nanofertilizers are regarded as the optimal solution because to their contribution to environmental sustainability (30). Iron is essential for plant functions, serving as a catalyst for enzymes in respiration and electron transport; it is also a crucial element of chloroplasts and several enzymes (12). Boron facilitates pollination and fertilization by promoting the growth of the pollen tube and its penetration into the ovule. Its substantial presence in the stigma and styles is crucial for fertilization, since it governs water absorption. Low boron levels result in increased water absorption by the pollen tube, perhaps causing it to rupture prior to reaching the ovule and complete fertilization (13). Boron is crucial for the synthesis and transport of carbohydrates from leaves to fruits, forming complexes comprising diverse cell walls constituents such as cellulose, hemicellulose, pectin, as well as lignin which are diminished in the tissues of cells affected by deficiency (27)

Seaweed extracts are organic inputs used in agricultural production, with about 15 million tons employed yearly in the sector. They pose no threat to healthy among people, animals, or natural surroundings. They enhance as well as control plant development, hence influencing Chemistry and biological properties for plants. They also include major and minor elements, amino acids, auxins, cytokinins, and polysaccharides. They also modulate osmosis at elevated concentrations and enhance plant resilience to salt, drought, and adverse environmental circumstances (21). They enhance nutrient absorption efficiency, mitigate load exchange phenomena, and promote photosynthesis and respiration processes. Furthermore, they possess antioxidant properties due to the presence of tocopherol, beta-carotene, niacin, thymine, and ascorbic acid, which augment enzyme activity (6). The research seeks to determine the ideal concentrations of boron and nano-iron injections, together with the effects of seaweed extract and their interactions on the vegetative and chemical properties and yield of apple trees.

## Materials and Methods

Location of the Experiment: The research has been carried out within a private apple orchard at village of Al-Bu-dhiyab situated 8 km west from Ramadi. The trees were grafted onto quince rootstock and were 5 years old, with uniform growth size as much as possible. The experiment was carried out from March 16, 2024, to July 1, 2024.

Execution of the Experiment: Five-year-old apple trees with uniform vegetative growth size were selected, planted in a spacing of (3×4) m for the purpose of conducting the experiment. Orchard maintenance operations, including irrigation, weeding, and fertilization, were performed uniformly across the trees. Soil analysis was conducted to determine soil chemicals as well as physiological property that showed in Table 1.

Four main branches were selected from the circumference of the trunk, and each branch was marked with tape for the purpose of taking measurements of the traits that will be studied.

**Table 1: Chemicals as well as physiological features of the Orchard soil.**

| Attributes | Values | Measurement units |
|---|---|---|
| **Electrical conductivity EC** | 1.41 | Deci-siemens $m^{-1}$ |
| **Total dissolved solids TDS** | 704 | mg. $l^{-1}$ |
| **PH** | 7.2 | ------- |
| **Soil separators** | | |
| **Clay** | 227.5 | gm $kg^{-1}$ |
| **Gilt** | 402.5 | gm $kg^{-1}$ |
| **Sand** | 370 | gm $kg^{-1}$ |
| **Tissue** Mixture | sandy loam | |
| **Nitrogen** | 0.29 | mg/$L^{-1}$ |
| **Phosphorus** | 0.8 | mg/$L^{-1}$ |
| **Attributes** | Values | Measurement units |
| **Potassium** | 1.32 | millimole $l^{-1}$ |
| **Calcium** | 10.6 | millimole $l^{-1}$ |
| **Magnesium** | 3.41 | millimole $l^{-1}$ |
| **Sodium** | 1.54 | millimole $l^{-1}$ |
| **Bicarbonate** | 1.72 | millimole $l^{-1}$ |
| **Carbonates** | Nil | |
| **Organic matter** | 1.7 | gm $kg^{-1}$ |
| **Gypsum** | 11.8 | gm kg-1 |
| **Lime** | 240 | gm kg-1 |
| **Exchange Capacity CEC** | 21 | Centimol. Shipment.$kg^{-1}$ |

Treatments and experimental design: The experiment was performed on 36 apple trees that exhibited maximal homogeneity in vegetative development. The experiment used two factors:

The first factor: This factor involved injecting tree trunks with elements of boron B (17) and iron Fe (24) nanoparticles at three different concentrations.

1. Injection with distilled water only, denoted as (N0).
2. Injection with Boron presented as orthoboric acid, $H_3BO_3$ with levels 10 mg $L^{-1}$ and injection with iron as $Fe_2O_3$ with levels 20 mg $L^{-1}$, denoted as (N1).
3. Injection with Boron presented as orthoboric acid $H_3BO_3$ with level 20 mg $L^{-1}$ and injection with iron as $Fe_2O_3$ with levels 40 mg $L^{-1}$, denoted as (N2).

A small hole with a diameter of 0.5 cm was drilled in the tree trunk at a height of 70 cm from the soil surface, where the nutrient solution was distributed using a 500 ml plastic tube, and the solution was delivered to the tree using a plastic tube with a distillation system.

The second factor: This factor involved the addition soil application of seaweed extract to apple trees at four different concentrations (2).

1. Soil application of water only, denoted as (A0).
2. Soil application of seaweed extract with levels of 3 mL $L^{-1}$, denoted as (A1).

3. Soil application of seaweed extract with levels 6 mL $L^{-1}$, denoted as (A2).
4. Soil application of seaweed extract with levels 9 mL $L^{-1}$, denoted as (A3).

Transaction Dates: The injection of nano-scale micronutrients and the incorporation of ground seaweed extract were carried out on the same day and at the times listed below.

• The first appointment was on March 16, 2024
• The second appointment will be on April 6, 2024
• The third appointment will be on April 26, 2024

Design of experiments the experiment included the injection of nanoelements at three concentrations and the addition of seaweed extract at four concentrations, using a randomized complete block design (R.C.B.D.) with three replicates, each representing one tree per treatment, overall quantity for trees is 36 (3×4×3). Duncan's test is used for comparing Averages for significant level of 0.05 (7).

Examined characteristics:

Characteristics of vegetative development:

1. Leaf Area ($cm^2$): Sixteen leaves were gathered from the central portions of the branches from various orientations at the beginning of June, and the leaf area was determined using the Dg mizier program:
2. Average chlorophyll content in leaves (mg 100 $g^{-1}$ fresh weight): Sixteen mature leaves were collected from the midsection of the new branches from various directions of the tree on 12/6/2024, and chlorophyll was estimated using the method of Bajracharya (10). The leaf samples were washed with distilled water to remove dust and impurities, then thoroughly dried and cut into small pieces to facilitate the extraction process. Next, 0.2 grams of each sample were taken, and extraction was performed using 10 ml of acetone (80% concentration). After completing the extraction process, the extract was collected, the sample's absorption is quantified using a spectrophotometer at specific wavelengths at 663 also 645 nanometers. Quantity for chlorophyll (mg $l^{-1}$). finally, the calculation using the following equation:

overall chlorophyll (mg $l^{-1}$) = 20.2 D (645) + 8.02 D (663)

D: wavelength reading, and the result was subsequently converted to (mg 100 $g^{-1}$ fresh weight).

3. Fruit Set Percentage (%): Four primary branches were chosen from each tree in various orientations, tagged accordingly, and the bloom count will be conducted on April 1, 2024. Subsequently, the fruit on each branch will be enumerated after a period of four weeks. The equation is used to calculate the percentage of fruit set as follows:

$$\text{Fruit setting percentage} = \frac{\text{Quantity of blooms produced after four weeks}}{\text{Total number of flowers}} \times 100$$

4. Average fruit weight (g): We randomly selected ten fruits from each tree and weighed them using a precise balance. Divide the overall fruit weight through their quantity to get the mean fruit weight.
5. Average fruit size ($cm^3$): We conducted this measurement on the same fruits whose weight we had previously recorded, using a graduated cylinder to

determine the fruit capacity based on the volume of water displaced. By summing the fruit volumes of the trees and dividing by their quantity, we get the average fruit volume.

6. Total yield (kg. tree$^{-1}$): The overall yield at the conclusion of the experiment was determined by multiplying the quantity of fruits by the mean fruit weight.
7. Total Sugar Concentration within Fruits (%): We estimated the total sugar amount in fruit using Joslyn's (22) method, which involved weighing 0.2 g of the specimen and adding 8 ml from 80% ethyl alcohol. We then placed the mixture inside a water bath at 60°C during thirty minutes. Next, we extracted fluid out of the filtrated by centrifuging at 3000 rpm via 15 minutes. We extracted residue a second time using ethyl alcohol. Next, we collected the filtrate and adjusted its volume to 50 ml using ethyl alcohol. From this, 1 ml has been put inside a testing tube, followed by adding of 1ml 5 ml concentrated sulfuric acid (98%), 5% phenol solution. The absorbance has been determined at 490 nanometers with a spectrophotometer following cooling the entire mixture, subsequent to calibrating the device through 80% ethyl alcohol. We plotted the readings on the glucose standard curve and multiplied the result by 50 to calculate the total sugar concentration in mg/g from the fruit pulp We dissolved 0.05, 0.10, 0.15, and 0.20 levels of glucose to make the sugar standard curve in 100 ml of d.w. Next, we added 1 ml of phenol solution and the aforementioned quantities of concentrated sulfuric acid. Finally, we calculated the absorbance values to obtain readings corresponding to these concentrations and drew a standard curve for glucose.
8. Total acidity in fruits (%): Ranganna (29) used a method to estimate overall fruit pulp acidic in percentage. We calibrated fruit juice with 0.1 molar NaOH and used a phenonphthalene indicator in accordance with the following equation:

$$\text{Total Acidity \%} = \frac{100 \times T \times N \times Eq.}{100 \times V}$$

Note that malic acid is the primary acid found in apples. formula and its symbol denote by following:

- T = size of the base utilized in the titre ($cm^3$).
- N = standard of the base utilized in the titre (0.1N).
- Eq. = equivalent weight of malic acid (22.33).
- V = volume of juice ($cm^3$).

9. Pectin percentage in fruits (%): We combined 0.5 g of mashed fruits with solutions, mixed well, rinsed with distilled water and sodium hydroxide (NaOH), and then performed filtering. Subsequently, we measured the mass of the precipitated substance, identified as pectin, to determine its percentage (1). We achieved this by use the below equation:

$$Pectin\ percentage = \frac{\text{Pectin weight}}{\text{Sample weight (0.5 g)}} \times 100$$

## Results and Discussion

Leaf Area ($cm^2$): The data in Table 2 demonstrate that the administration of micronutrient elements (Fe+B) significantly influenced the leaf area of apple plants.

Treatment N2 (40Fe+20B mg $L^{-1}$) exhibited the greatest measurement of 35.43 cm², while treatment N1 (20Fe+10B mg $L^{-1}$) showed a value of 31.56 cm², and treatment N0 (injection with distilled water alone) yielded the lowest measurement of 22.74 cm². Treatment A3 (9 mL $L^{-1}$) of seaweed extract significantly influenced leaf area, achieving the greatest measurement of 32.00 cm², while treatment A0 (distilled water alone) recorded the lowest at 28.00 cm². The interaction of the research components revealed that treatment N2A3 had a substantial impact, measuring 37.92 cm², while the control treatment N0A0 exhibited the lowest measurement of 19.96 cm².

**Table 2: Effect of micronutrient nanoparticles injection and seaweed extract application and their interaction on leaf area(cm²).**

| Injection of micro-elements N(Fe+B) | Add seaweed extract A | | | | Mean |
|---|---|---|---|---|---|
| | A0 (distilled water only) | A2 (6 ml $L^{-1}$) | A2 (6 ml $L^{-1}$) | A3 (9 ml $L^{-1}$) | |
| **N0 (distilled water only)** | 19.96g | 22.73fg | 25.36ef | 22.89fg | **22.74c** |
| **N1 (10+20mg $L^{-1}$)** | 29.36de | 30.40cd | 31.22bcd | 35.28ab | **31.56b** |
| **N2 (20+40mg $L^{-1}$)** | 34.69abc | 34.71abc | 34.42abc | 37.92a | **35.43a** |
| **Mean** | **28.00b** | **29.28b** | **30.34ab** | **32.00a** | |

Content of total chlorophyll in leaves (mg $100g^{-1}$ fresh weight): The results presented in Table 3 indicate that injecting apple trees with micronutrient nanoparticles significantly increased the total chlorophyll content in the leaves, with treatment N2 achieving the highest value of 116.00 mg $100g^{-1}$ fresh weight compared to treatment N0, which had the lowest value of 88.58 mg $100g^{-1}$ fresh weight. The addition of seaweed extract showed a significant effect at treatment A3, which reached the highest value of 107.00 mg $100g^{-1}$ fresh weight and did not differ significantly from treatments A2 and A1, which had values of 106.00 and 105.44 mg $100g^{-1}$ fresh weight, respectively, while treatment A0 recorded the lowest value of 102.22 mg $100g^{-1}$ fresh weight. The interaction between the study factors demonstrated a significant effect at treatment N2A3, which recorded the highest value of 117.67 mg $100g^{-1}$ fresh weight and did not differ significantly from treatments N2A2 and N2A1, which had values of 117.33 and 116.33 mg $100g^{-1}$ fresh weight, respectively, compared to treatment N0A0, which had the lowest value of 85.67 mg $100g^{-1}$ fresh weight.

**Table 3: Effect of micronutrient nanoparticles injection and seaweed extract application and their interaction on the total chlorophyll content in leaves (mg $100g^{-1}$ fresh weight).**

| Injection of micro-elements N(Fe+B) | Incorporate seaweed extract A | | | | Mean |
|---|---|---|---|---|---|
| | A0 (distilled water only) | A1(3 ml $L^{-1}$) | A2(6 ml $L^{-1}$) | A3(9 ml $L^{-1}$) | |
| **N0 (distilled water only)** | 85.67e | 88.67de | 89.00de | 91.00d | **88.58c** |
| **N1 (10+20mg $L^{-1}$)** | 108.33c | 111.33bc | 111.67bc | 112.33b | **110.92b** |
| **N2 (20+40mg $L^{-1}$)** | 112.67b | 116.33a | 117.33a | 117.67a | **116.00a** |
| **Mean** | 102.22b | 105.44a | 106.00a | 107.00a | |

Percentage of Fruit Set (%): The study factors significantly affected the percentage of fruit set, as observed from the results in Table 4, which demonstrate a clear significant effect of injecting micro nanoparticles on the fruit set percentage of apple trees. The treatment N2 recorded the highest percentage at 42.90%, while treatment N0 recorded the lowest percentage at 33.83%. Regarding the different levels of addition of the seaweed extract, treatment A3 showed a significant effect with the highest percentage at 40.87%, and it was not significantly different from treatments A2 and A1, which recorded percentages of 40.30% and 38.88%, respectively, while treatment A0 recorded the lowest percentage at 35.91%.

The interaction between the study factors also showed a significant effect on the percentage of fruit set, with treatment N2A3 achieving the highest fruit set percentage at 43.54% compared to treatment N0A0, which recorded the lowest percentage at 26.18%.

**Table 4: Effect of micronutrient nanoparticles injection and seaweed extract application and their interaction on the fruit set (%).**

| Injection of micro-elements N(Fe+B) | Add seaweed extract A | | | | Mean |
|---|---|---|---|---|---|
| | A0 (distilled water only) | A1 (3 ml $L^{-1}$) | A2 (6 ml $L^{-1}$) | A3 (9 ml $L^{-1}$) | |
| **N0 (distilled water only)** | 26.18d | 33.80c | 37.55bc | 37.78bc | **33.83c** |
| **N1 (10+20mg $L^{-1}$)** | 39.04ab | 40.28ab | 40.37ab | 41.28ab | **40.24b** |
| **N2 (20+40mg $L^{-1}$)** | 42.51ab | 42.55ab | 42.98a | 43.54a | **42.90a** |
| **Mean** | 35.91b | 38.88a | 40.30a | 40.87a | |

Average weight of the fruit (g): The results in Table 5 indicate a significant difference in the average weight of the fruit from apple trees due to the injection of nano-micronutrients, with treatment N2 recording the highest value of 75.4 g, while treatment N1 recorded 69.0 g, and treatment N0 recorded the lowest value of 58.6 g. Regarding the addition of seaweed extract, treatment A3 showed a significant effect with a value of 72.7 g, while treatment A0 recorded the lowest value of 61.6 g. The interaction of the two factors studied demonstrated a clear significant effect in treatment N2A3, which recorded the highest value of 80.7 g, whereas the control treatment N0A0 recorded the lowest value of 44.1 g.

**Table 5: Effect of micronutrient nanoparticles injection and seaweed extract application and their interaction on the fruit weight (g).**

| Injection of micro-elements N(Fe+B) | Add seaweed extract A | | | | Mean |
|---|---|---|---|---|---|
| | A0 (distilled water only) | A1 (3 ml $L^{-1}$) | A2 (6 ml $L^{-1}$) | A3 (9 ml $L^{-1}$) | |
| N0 (distilled water only) | 44.1d | 61.1c | 62.0bc | 67.4abc | 58.6c |
| N1 (10+20mg $L^{-1}$) | 68.7abc | 67.8abc | 69.7abc | 70.0abc | 69.0b |
| N2 (20+40mg $L^{-1}$) | 72.0abc | 73.4abc | 75.7ab | 80.7a | 75.4a |
| Mean | 61.6b | 67.4ab | 69.1ab | 72.7a | |

Average size of the fruit ($cm^3$): The results in Table 6 showed a significant effect of injecting a mixture of nano-micronutrients on the average size of the fruit from apple trees, with treatment N2 recording the highest value of 109.2 $cm^3$ compared to treatment N0, which recorded the lowest value of 87.9 $cm^3$. Regarding the addition of seaweed extract, treatment A3 demonstrated its significant effect on average fruit size, recording the highest value of 105.50 $cm^3$ compared to treatment A0, which recorded 94.40 $cm^3$. The interaction of the two factors studied showed a significant effect on average fruit size, with treatment N2A3 recording the highest value of 112.2 $cm^3$ compared to the control treatment N0A0, which recorded the lowest value of 78.60 $cm^3$.

**Table 6: Effect of micronutrient nanoparticles injection and seaweed extract application and their interaction on fruit size ($cm^3$).**

| Injection of micro-elements N(Fe+B) | Add seaweed extract A | | | | Mean |
|---|---|---|---|---|---|
| | A0 (distilled water only) | A1 (3 ml $L^{-1}$) | A2 (6 ml $L^{-1}$) | A3 (9 ml $L^{-1}$) | |
| N0 (distilled water only) | 78.60d | 84.10cd | 91.90bcd | 97.10abc | 87.90b |
| N1 (10+20mg $L^{-1}$) | 97.30abc | 98.40abc | 101.70abc | 107.30ab | 101.20b |
| N2 (20+40mg $L^{-1}$) | 107.30ab | 107.70ab | 109.50ab | 112.20a | 109.20a |
| Mean | 94.40b | 96.70ab | 101.00ab | 105.50a | |

Total Yield (kg $tree^{-1}$): The results presented in Table 7 indicate that injecting micronutrients significantly influenced the overall yield of apple trees. Treatment N2 recorded the highest yield at 74.50 kg $tree^{-1}$, followed by treatment N1 with 68.67 kg $tree^{-1}$, while treatment N0 had the lowest yield at 62.92 kg $tree^{-1}$. Regarding the addition of seaweed extract, treatment A3 demonstrated a significant effect on total yield, achieving the highest value of 72.33 kg $tree^{-1}$. Treatments A2 and A1 recorded yields of 70.00 and 68.11 kg $tree^{-1}$, respectively, whereas treatment A0 had the lowest yield at 64.33 kg $tree^{-1}$. In terms of the interaction between the study factors, treatment N2A3 exhibited the most significant effect, reaching a yield of 80.33 kg $tree^{-1}$, while the control treatment N0A0 recorded the lowest yield at 57.67 kg $tree^{-1}$.

**Table 7: Effect of micronutrient nanoparticles injection and seaweed extract application and their interaction on yield (kg tree$^{-1}$).**

| Injection of micro-elements N(Fe+B) | Add seaweed extract A | | | | Mean |
|---|---|---|---|---|---|
| | A0(distilled water only) | A1 (3 ml L$^{-1}$) | A2 (6 ml L$^{-1}$) | A3 (9 ml L$^{-1}$) | |
| N0 (distilled water only) | 57.67h | 63.67g | 64.00fg | 66.33ef | 62.92c |
| N1 (10+20mg L$^{-1}$) | 65.67fg | 68.33de | 70.33cd | 70.33cd | 68.67b |
| N2 (20+40mg L$^{-1}$) | 69.67d | 72.33c | 75.67b | 80.33a | 74.50a |
| Mean | 64.33d | 68.11c | 70.00b | 72.33a | |

Total Sugar Content in Fruits (%): The data in Table 8 demonstrate that the injection of a micronutrient combination substantially influenced the total sugar content in apple tree fruits. Treatment N2 had the greatest sugar concentration at 12.43%, whilst treatment N0 demonstrated the lowest at 10.16%. The incorporation of seaweed extracts significantly influenced sugar content, with treatment A3 attaining the greatest percentage of 11.75%, whilst treatment A0 exhibited the lowest at 10.90%. The interactions among the research variables significantly influenced the overall sugar content in the fruits. The therapy N2A3 achieved the greatest percentage at 12.93%, closely followed by treatment N2A2 at 12.86%, while treatment N0A0 recorded the lowest percentage at 9.93%.

**Table 8: Effect of micronutrient nanoparticles injection and seaweed extract application and their interaction on total sugars (%).**

| Injection of micro-elements N(Fe+B) | Add seaweed extract A | | | | Mean |
|---|---|---|---|---|---|
| | A0(distilled water only) | A1 (3 ml L$^{-1}$) | A2 (6 ml L$^{-1}$) | A3 (9 ml L$^{-1}$) | |
| N0 (distilled water only) | 9.93g | 10.16fg | 10.16fg | 10.40f | 10.16c |
| N1 (10+20mg L$^{-1}$) | 10.96e | 11.40d | 11.30d | 11.93bc | 11.40b |
| N2 (20+40mg L$^{-1}$) | 11.80c | 12.13b | 12.86a | 12.93a | 12.43a |
| Mean | 10.90d | 11.23c | 11.44b | 11.75a | |

Total Acidity Percentage in Fruits (%): The results presented in Table 9 clearly demonstrate the significant effect of injecting micronutrients on the total acidity percentage in the fruits of apple trees. The treatment N2 recorded the lowest acidity percentage at 0.3000%, while the treatment N0 recorded the highest at 0.4058%. Regarding the different levels of seaweed extract addition, the treatment A3 showed a significant effect with the lowest percentage of 0.3356%, while the treatment A0 had the highest percentage at 0.3644%. The interaction between the study factors significantly affected the total acidity percentage in the fruits, with the treatment N2A3 recording the lowest acidity percentage of 0.2733% compared to the treatment N0A0, which recorded the highest at 0.4233%.

**Table 9: Effect of micronutrient nanoparticles injection and seaweed extract application and their interaction on acidity (%).**

| Injection of micro-elements N(Fe+B) | Add seaweed extract A | | | | Mean |
|---|---|---|---|---|---|
| | A0(distilled water only) | A1 (3 ml $L^{-1}$) | A2 (6 ml $L^{-1}$) | A3 (9 ml $L^{-1}$) | |
| **N0 (distilled water only)** | 0.4233f | 0.4100ef | 0.4067e | 0.3833d | **0.4058c** |
| **N1 (10+20mg $L^{-1}$)** | 0.3567c | 0.3467c | 0.3467c | 0.3500c | **0.3500b** |
| **N2 (20+40mg $L^{-1}$)** | 0.3133b | 0.3100b | 0.3033b | 0.2733a | **0.3000a** |
| **Mean** | 0.3644c | 0.3556b | 0.3522b | 0.3356a | |

Pectin Content in Fruits (%): The study treatments significantly affected the pectin content in the fruits, as observed from the results in Table 10, which show a clear significant difference due to the injection of micronutrients in the pectin content of apple tree fruits. The treatment N2 recorded the highest percentage at 1.489%, compared to treatment N0, which recorded the lowest percentage at 1.210%. The addition of seaweed extracts also had a significant effect on the pectin content in the fruits, with treatment A3 recording the highest percentage at 1.426%, compared to treatment A0, which recorded the lowest percentage at 1.312%. The interaction between the two study factors significantly affected the pectin content in the fruits, with N2A3 recording the highest percentage at 1.576%, compared to treatment N0A0, which recorded the lowest percentage at 1.186%.

**Table 10: Effect of micronutrient nanoparticles injection and seaweed extract application and their interaction on pectin content (%).**

| Injection of micro-elements N(Fe+B) | Add seaweed extract A | | | | Mean |
|---|---|---|---|---|---|
| | A0(distilled water only) | A1 (3 ml $L^{-1}$) | A2 (6 ml $L^{-1}$) | A3 (9 ml $L^{-1}$) | |
| **N0 (distilled water only)** | 1.186g | 1.206fg | 1.210fg | 1.240f | **1.210c** |
| **N1 (10+20mg $L^{-1}$)** | 1.350e | 1.393d | 1.393d | 1.463c | **1.400b** |
| **N2 (20+40mg $L^{-1}$)** | 1.400d | 1.470c | 1.510b | 1.576a | **1.489a** |
| **Mean** | 1.312c | 1.356b | 1.371b | 1.426a | |

Tables 2-10 present results demonstrating the impact of boron and nano-iron injections on various vegetative and chemical growth characteristics and yield, especially when administered at a concentration of 20 mg $L^{-1}$ boron and 40 mg $L^{-1}$ iron. The reason for this superiority is due to the mineral elements included in the composition of the nutrient solution combination, as boron plays a major role in the formation of the cell wall, cell division, and raising the rate of photosynthesis. It also has significant importance in increasing proteins and carbohydrates and transferring sugars from their manufacturing sites in the leaves to the various growth and storage areas in the plant (28). The findings align with those of Kassem et al. (23) on apple trees and Muhammad (26) on lemon trees.

One of the components of the nutrient combination, boron, plays a major role in the pollination and fertilization processes, stimulating the growth of the pollen tube and its penetration into the ovule (5). Due to its significant presence in the stigmas and style, boron also plays a crucial role in fertilization. It regulates water absorption, causing the pollen tube to absorb more water when its levels drop, which leads to an explosion before it reaches the ovule and completes fertilization (9).

It facilitates cell division and enhances the size and weight of the fruits. The rise in the proportion of knots correlates directly with the enlargement of the fruits, resulting in an augmentation of the overall yield (14). Elevating the boron content within acceptable limits enhances the photosynthetic process. Boron is essential for synthesizing the sugars required for fruit development and minimizing competition among them for resources produced by the leaves. It also significantly contributes to the production and transport of carbohydrates from the leaves to the fruits. It forms compounds with many cell wall constituents, including cellulose, hemicellulose, pectin, and lignin. This subsequently diminishes in cellular tissues affected by its absence (31). These findings align with the observations made by (23) about apple trees, (26) concerning lemon trees, and the conclusions drawn by (19) and the conclusions drawn by (20)

According to (33), iron enhances chlorophyll synthesis, increasing its concentration in the leaves. This, in turn, leads to increased photosynthesis efficiency. This, in turn, increases the amount of carbohydrates manufactured in the leaves and stored in the fruits, thereby increasing the fruit's size, weight, and overall yield. Iron is essential to enhance photosynthesis processes and improve the transfer of carbohydrates to different parts (25). These results are consistent with what (16) mentioned in their study on pomegranate trees.

The results in Tables 2–10 show that adding seaweed extract had a clear effect on all growth characteristics at a concentration of 9 ml $L^{-1}$. This is because the seaweed makes the photosynthesis process more efficient, which increases the production of pigments like chlorophyll and carotene. Additionally, it plays a crucial role in preserving the plasma membranes, which positively impacts the leaf area and boosts its chlorophyll content (3 and 4). The superiority of seaweed extract addition treatments stems from their beneficial effects on the photosynthesis process, respiration, and cellular metabolism. They integrate into the nucleic acid composition, which is essential for cell division and the creation of proteins, enzymes, and hormones (8).

## Conclusions

This study found that injecting nanoparticle fertilizers into tree trunks was a quick, cheap, and very effective way to treat deficiency cases at different stages of growth at a level of B20+ Fe40 mg $L^{-1}$. Moreover, the application soil of seaweed extract yielded positive outcomes across all characteristics, particularly at a concentration of 9 ml $L^{-1}$.

**Supplementary Materials:**

No Supplementary Materials.

**Author Contributions:**

All authors reviewed and approved the published version of the work.

**Funding:**

This research received no external funding.

**Institutional Review Board Statement:**

The study was conducted following the protocol authorized by the Head of the Ethics Committee, University of Anbar, Iraq Republic.

**Informed Consent Statement:**

No Informed Consent Statement.

**Data Availability Statement:**

No Data Availability Statement.

**Conflicts of Interest:**

The authors declare no conflict of interest.

**Acknowledgments:**

The authors gratefully acknowledge the assistance provided by the College Dean of the College of Agriculture, University of Anbar, Iraq.

**Disclaimer/Journal's Note:**

The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of AJAS and/or the editor(s). AJAS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

## References

1. A.O.A.C. (1980). Official Methods of Analysis. 13th ed. Association of Official Analytical Chemists. Washington, D.C.
2. Abdulrhman, A. S., and Al-Atrushy, S. M. (2024). Effect of bio health, tecamin max and benzyl adenine on growth characteristics of sweet orange seedlings. Iraqi Journal of Agricultural Sciences, 55(1), 605-617.
3. Al-Doori, M. F., and Hussein, S. A. (2024). Effect of vine load and seaweed extract on the growth and yield of grape vines (vitis vinifera l.), shatter al-anz cultivar. Anbar Journal of Agricultural Sciences, 22(2): 1007-1018. https://doi.org/10.32649/ajas.2024.148012.1179.
4. Al-dulimi, S. Y., and Al-Ali, H. H. (2024). Effect of ground fertilization with humic acid and spraying with seaweed extract and baking yeast and their effect on the bukthorn tafahe seedling. Anbar Journal of Agricultural Sciences, 22(1): 115-128. https://doi.org/10.32649/ajas.2024.183705.
5. Al-Janabi, A. M. I. (2024). Impact of gibberellic acid and boron trioxide nanoparticles foliar spraying on growth, yield and fruit quality of" zaghinia" apricot trees. Anbar Journal of Agricultural Sciences, 22(2): 1557-1569. https://doi.org/10.32649/ajas.2024.184887.
6. Al-Mohammadi, M. M., and Al-Dolaimi, R. M. (2024). The Effect of Adding Nano NPK Fertilizer EM1 biofertilizer and Spraying with Algae Extract on some Growth Characteristics and Yield of Date Palm Variety Khastawi. In IOP Conference Series: Earth and Environmental Science, 1371(4): p. 042006. DOI: 10.1088/1755-1315/1371/4/042006.
7. Al-Mohammadi, S. M., and Al-Mohammadi, F. M. (2012). Statistics and experimental design. Dar Osama for publishing and distribution. Amman, Jordan, 376.

8. Al-Sahhaf, F. H. R. (1989). Applied plant nutrition. Ministry of Higher Education and Scientific Research. University of Baghdad. House of Wisdom. Iraq.
9. Al-Sharif, A. (1995). Basics of Modern Horticulture, Omar Al-Mukhtar University Publications, Libya.
10. Bajracharya, R. M., and Lal, R. (1999). Land use effects on soil crusting and hydraulic response of surface crusts on a tropical Alfisol. Hydrological Processes, 13(1): 59-72. https://doi.org/10.1002/(SICI)1099-1085(199901)13:1%3C59::AID-HYP675%3E3.0.CO;2-1.
11. Bal, J. S. (2005). Fruit growing 3rd etd. Kalyani Publisher, New Delhi- 110002.
12. Barker, A. V., and Stratton, M. L. (2015). Iron. Chapter 11 In: Barker, A. V., and Pilbeam, D. J. (eds): Handbook of plant nutrition. Second Edition CRC press Taylor and Francis group. London. New York, 399-426.
13. Bons, H. K., and Sharma, A. (2023). Impact of foliar sprays of potassium, calcium, and boron on fruit setting behavior, yield, and quality attributes in fruit crops: a review. Journal of Plant Nutrition, 46(13): 3232-3246. https://doi.org/10.1080/01904167.2023.2192242.
14. Daniel, R. - Translated by Muhammad, K., Jamal, I., Yahya, A. A., and Ahmed, Z. (1992). Plant Diseases, Arab Publishing and Distribution House, Cairo, Egypt.
15. Das, H. S., Basak, A., and Maity, S. (2025). Materials Science and Nanotechnology. In Innovations in Energy Efficient Construction Through Sustainable Materials, 175-206.
16. Davarpanah, S., Tehranifar, A., Zarei, M., Aran, M., Davarynejad, G., and Abadía, J. (2020). Early season foliar iron fertilization increases fruit yield and quality in pomegranate. Agronomy, 10(6): 832. https://doi.org/10.3390/agronomy10060832.
17. El-Salhy, A. F. M., Masoud, A. A., Gouda, F. E. Z., Saeid, W. T., and Abd El-Magid, E. A. (2022). Effect of foliar spraying of calcium and boron nano-fertilizers on growth and fruiting of certain pomegranate cultivars. Assiut Journal of Agricultural Sciences, 53(5): 123-138. https://dx.doi.org/10.21608/ajas.2022.154162.1162.
18. Fadam, M. A. N., and Hamad, M. R. (2023). Response of pomegranate seedlings cv. salimi to foliar spraying with chelated iron and nutrient solution prosol and proline. Anbar Journal of Agricultural Sciences, 21(2): 549-562. https://doi.org/10.32649/ajas.2023.179754.
19. Harhash, M. M., Ali, M. A., Abd El-Megeed, N., and Ben Hifaa, A. B. (2019). Effect of some growth regulators, nutrient elements and kaolin on cracking and fruit quality of pomegranate ‘Wonderful’cultivar. Journal of the Advances in Agricultural Researches, 24(3): 280-297. https://dx.doi.org/10.21608/jalexu.2019.163427.
20. Hilal, T. A., and Al-Falahy, T. H. (2024). Impact of exogenous ascorbic acid and putrescine on vegetative, root system morphology and chemical composition of clementine Mandarin saplings. HORIZON, 11(3): 527-534. https://doi.org/10.14719/pst.4075.
21. Jensen, E. (2004). Fact or fancy. From the organic broad caster. Midwest organic and Sustainable. Education, 12(3): 164-170.

22. Joslyn, M. A. (1970). Method in Food Analysis, Physical, Chemical, and Instrumental Methods of Analysis. 2nd ed. Academic Press, New York and London.
23. Kassem, H., Marzouk, H., and El-Kobbia, A. (2016). Response of Anna apples yield, quality, and storage potential to boron and/or zinc foliar sprays. J. Sci. Eng. Res, 3(5): 144-152.
24. Khazaal, Z. (2023). Effect of Foliar Spraying with Nano Iron and Ascorbic Acid on the Vegetative and Fruiting Growth of Lemon. Euphrates journal of agricultural science, 15(1): 118-126.
25. Mahmoud, A. W. M., Abdelaziz, S. M., El-Mogy, M. M., and Abdeldaym, E. A. (2019). Effect of foliar ZnO and FeO nanoparticles application on growth and nutritional quality of red radish and assessment of their accumulation on human health. Agriculture, 65(1): 16-29. DOI: 10.2478/agri-2019-0002.
26. Muhammad, N. D. (2018). The effect of different levels and dates of foliar spraying with some trace elements (B, Zn, Fe) and some biological, morphological and production specifications of “Meyer” lemon trees. Doctoral thesis. Tishreen University, Department of Horticulture.
27. Oudah, M. A., and Hamad, R. M. (2024). Effect of Shading and Foliar Spraying with Nutrient Solution on Vegetative Growth and Yield Traits of Sweet Orange Trees cv. Local. In IOP Conference Series: Earth and Environmental Science, 1371(4): p. 042010. DOI: 10.1088/1755-1315/1371/4/042010.
28. Prathima, A. S., Rohini, N. M., and Shivaramu, H. S. (2016). Influence of boron seed treatment on seed germination, seedling length and seedling vigor in sunflower (Helianthus annuus L.). International Journal of Science and Nature, 7(2): 273-276.
29. Ranganna, S. (1977). Manual Analysis of fruit and Vegetable Products Tata. McGraw –Hill Publishing Company Limited, New Delhi.
30. Ridhi, R., Saini, G. S. S., and Tripathi, S. K. (2024). Nanotechnology as a sustainable solution for proliferating agriculture sector. Materials Science and Engineering: B, 304: 117383. https://doi.org/10.1016/j.mseb.2024.117383.
31. Shaban, M. (2010). Role of boron in plant nutrition and human health. Amwr. J. plant physiol, 5(5): 224-240. https://doi.org/10.3923/ajpp.2010.224.240.
32. Shang, S., Zhou, H., Chang, X., Liu, M., Li, N., and Shang, Q. (2014). Study on factors of inject large volume liquid into trunk. Math Model Eng Probl, 1(1): 11-14. http://dx.doi.org/10.18280/mmep.010203.
33. Tomljenović, N., Jemrić, T., and Vuković, M. (2022). Diversity of the genus Rosa pomological traits in ecological conditions of continental Croatia. Genetika, 54(2): 689-704. https://doi.org/10.2298/GENSR2202689T.
34. Vejan, P., Khadiran, T., Abdullah, R., and Ahmad, N. (2021). Controlled release fertilizer: A review on developments, applications and potential in agriculture. Journal of controlled Release, 339: 321-334. https://doi.org/10.1016/j.jconrel.2021.10.003.