Egypt. J. Soil Sci. Vol **.65**, No. 3, pp: 1273 - 1284 (2025)

Egyptian Journal of Soil Science
http://ejss.journals.ekb.eg/

Optimizing Maize Productivity in Salt-Affected Soils Using Magnesium, Wood Vinegar and Seaweed

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THE NECESSITY for new, environmentally friendly agricultural strategies is critical for maximizing the production of strategic crops like maize, especially in light of challenges posed by degraded soils, such as salt-affected soils. Moreover, it is essential to focus on the role of often-overlooked elements in agricultural programs, such as magnesium, which plays a vital role in forming oil as a co-enzyme in oil crops and improving crop growth and quality. So, a field experiment was implemented to investigate the impacts of different treatments on maize grown on salt affected soil. The treatments of main factor included magnesium sulphate at rates of 0, 50 and 100 kg fed^{-1} , while the treatments of the sub-main factor included spraying bio stimulants [control (without foliar application), seaweed at two rates (7.5 and 15 g L^{-1}) and wood vinegar at two rates (2 and 4 ml L^{-1})]. The results show that applying magnesium sulphate at rate of 50 and 100 kg fed^{-1} had a significant influence on promoting maize growth under salt-affected soil circumstances. There were significant increases in the protein, carbohydrate, oil and anthocyanin contents in the grains compared to control treatments. Generally, the maize plants sprayed with seaweed extract or wood vinegar possessed higher antioxidant activity, that helped mitigate the oxidative caused by salinity stress. Using these treatments also led to substantial improvements in the maize productivity and grain quality. Generally, these findings emphasize the importance of integrating elements such as Mg into agricultural programs, particularly when cultivating under degraded soil conditions. They also highlight the need to adopt new agricultural practices which improve the use of natural extracts, like seaweed and wood vinegar, to bolster crops' resilience in harsh environmental circumstances.

Keywords: Degraded soils, Agricultural programs, Magnesium, Wood vinegar and Seaweed.

1. Introduction

The Egyptian government is currently working to rehabilitate most of its degraded lands to address the growing challenges and increase agricultural productivity to bridge the food gap (**Elsonbaty and El-Sherpiny, 2024)**. Many of the country's agricultural soils suffer from a gradual annual increase in salinity due to reliance on agricultural drainage water for irrigation purposes (**El-Sherpiny *et al*. 2023)**. Hence, there is an urgent need to integrate innovative strategies into the agricultural sector to enhance soil health and crop productivity (**Elbaalawy *et al.* 2023)**.

In this context, it can be argued that there are often overlooked nutrients, such as magnesium, which may play an important role in improving plant growth in salt-affected soils. Magnesium is essential for various physiological processes in plants, such as photosynthesis and enzyme activation. Mg serves as the central atom in the chlorophyll molecule and as an essential cofactor in many enzymatic reactions related to energy transfer. Moreover, one of magnesium's most critical roles is as a coenzyme in oil formation in oil crops (**Soliman *et al.* 2024).** Its application improves nutrient uptake and promotes overall plant health, making it an important factor to consider in agricultural practices in degraded lands. Under saline circumstances, Mg availability and mobility are often disrupted, leading to impaired growth and metabolic dysfunction **(Jaiswal *et al.* 2021).**

The use of environmentally friendly materials, such as wood vinegar and seaweed extracts, also plays a significant and effective role in improving crop performance under environmental stress conditions. Wood vinegar is rich in organic acids and phenolic compounds, which provide strong antioxidant and antimicrobial properties, helping plants withstand oxidative stress and pathogen threats. It also promotes healthy growth and

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Received: 05/05/2025; Accepted: 14/06/2025
DOI: 10.21608/ejss.2025.381943.2159

improves grain quality. Thus the wood vinegar, due to its components, enhances higher plants resilience by enhancing antioxidant capacity **(Akley *et al.* 2023; El-Fawy *et al.* 2024).** On the other hand, seaweed extracts contain bioactive compounds that improve photosynthesis, nutrient uptake, and tolerance to environmental stress. They also contain growth hormones that stimulate cell division and elongation, improving crop productivity under environmental stress conditions. In other words, seaweed extract is rich in components that collectively enhance higher plants resilience by enhancing osmotic balance and antioxidant capacity **(Hussein *et al.* 2021; Fatima *et al.* 2024).**

Maize (*Zea mays*) was chosen for this investigation due to its strategic importance as a primary food source and its high protein content, making it a important component of livestock feed (**Farid *et al.* 2023)**. Demand for maize is growing, and improving its production in degraded and salt-affected soils is essential to ensuring food security and supporting the livestock sector.Therefore, the main objective of this research is to investigate the impact of magnesium application in raising the oil content in maize, along with environmentally friendly materials, in raising plant tolerance to the harmful effects of salt-affected soils.

2. Material and Methods

A field experiment was conducted in Met-Antar village, Talkha district, El-Dakahlia Governorate, Egypt (coordinates: 31°4'54"N, 31°24'4"E) during the 2023 and 2024 growing summer seasons. The study utilized a split-plot design with three replications to evaluate the response of maize (cv. Yaqout single hybrid) grown on salt-affected soil to magnesium, wood vinegar and seaweed treatments. The main plot factor involved magnesium soil amendments with three treatments: Control (without magnesium), $MgSO_4$ at 50 kg fed^{-1} and $MgSO_4$ at 100 kg fed^{-1}. The sub-main plots included foliar applications of bio stimulants, with treatments consisting of a control (without foliar application), seaweed at two rates (7.5 and 15 g L^{-1}) and wood vinegar at two rates (2 and 4 ml L^{-1}). Each plot measured 12.0 m² (4.0 m width × 3.0 m length), consisting of 6 rows, each 0.85 m apart. Maize plants were spaced at 30.0 cm within rows. The experimental flowchart is presented in Fig 1.

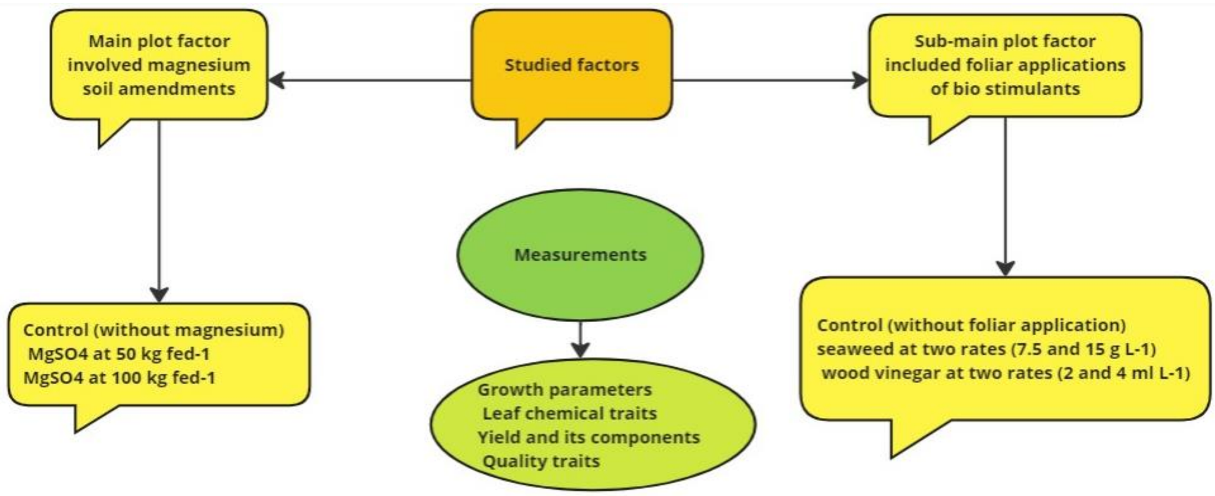

Fig. 1. Experimental flowchart

The initial soil, along with wood vinegar and seaweed extract, were analyzed according to **Tandon (2005)** methodology, with their properties detailed in Table 1. When the available magnesium in the soil is less than 100 mg per kg of soil, it is considered poor in magnesium **(Tisdale, 1985; Behera *et al.* 2021),** as mentioned by **El-Fouly *et al.* (2010)** who reported the Mg depletion in the Egyptian soil with time. The same table also includes key characteristics of magnesium sulphate. All substances examined were sourced from the commercial Egyptian market.

Table 1. The characteristics of initial soil and substances studied.

Initial soil			
Properties	**Values**	**Properties**	**Values**
Clay,%	52.41	**EC,dSm^{-1}**	4.35
Silt,%	21.38	**pH**	8.02
Sand,%	26.21	**ESP**	10.5
Texture class is clay		**SAR**	7.10
		Organic matter,%	1.35
		Nitrogen, mg kg^{-1}	29.3
		Phosphorus, mg kg^{-1}	5.95
		Potassium, mg kg^{-1}	189.3
		Magnesium, mg kg^{-1}	60.0

Substances Studied			
Category	**Wood Vinegar**	**Seaweed extract**	**Magnesium sulphate**
Source	Produced from the thermal distillation of wood (pyrolysis).	Extracted from various species of seaweed.	A chemical compound ($MgSO_4$) naturally occurring as epsomite.
Chemical Composition	Contains organic acids (*e.g.*, acetic acid, 5%), alcohols (*e.g.*, methanol, 1%), and phenolic compounds (*e.g.*, guaiacol, 0.5%).	Rich in minerals (*e.g.*, iodine ~0.04%, potassium, 1%), vitamins, and plant growth hormones like cytokinins.	Composed of magnesium (16%), sulfur (13%), and oxygen. Molecular mass is 120.366 g mol^{-1}. Melting point is 1.124 °C. Density is 2.66 g cm^3.
Primary benefits	Enhances microbial activity in the soil, reduces odors, and stimulates plant growth.	Promotes growth, increases stress resistance, and improves crop quality.	Provides essential magnesium and sulfur, crucial for chlorophyll formation and enzyme activation.

Seeds were sown on May 1st in both growing seasons, following the standard agronomic practices recommended by the Ministry of Agriculture and Soil Reclamation. Magnesium sulphate was incorporated into the soil during the land preparation process. Foliar applications of the studied biostimulants were conducted three times throughout the growing season, specifically at 30, 45 and 60 days after sowing. The cobs and stover of maize were harvested 90 days after sowing.

Data collection

1- Silk extrusion stage

Growth criteria: Plant height, fresh and dry weights, and leaf area were measured.

Photosynthetic pigments: Chlorophyll a, chlorophyll b, and carotene were measured spectrophotometrically using 80% acetone, following the method described by **Porra *et al.* (1989).**

Leaf analysis: Leaf samples were digested with a mixture of perchloric and sulfuric acids, following the procedure outlined by **Peterburgski (1968).**

Nutrient determination: Nitrogen content was analyzed using the Micro-Kjeldahl technique, phosphorus was quantified spectrophotometrically and potassium levels were determined using a flame photometer, as recommended by **Walinga *et al.* (2013).**

Antioxidant assessment: The levels of non-enzymatic antioxidants, including proline, were evaluated to gauge the plant's response to oxidative stress, following the method described by **Ábrahám *et al.* (2010).** Furthermore, indicators of oxidative damage, such as malondialdehyde (MDA), were measured using the approach detailed by **Valenzuela (1991).**

2- At period of 90 days (harvest stage)

Yield parameters: Cob length, cob weight, the weight of 100 grains, grain yield, biological yield and harvest index were recorded.

Nutrient analysis: The nutrient content (NPK) in the grains was determined using the same procedures as those applied to the leaves. Nutrient uptake was calculated by multiplying the concentration of each element (NPK) by the grain crop's weight (Nutrient uptake= nutrient concentration x grain crop's weight).

Seed quality: Carbohydrate content was determined using the Anthrone method according to **AOAC (2000).** Protein content was derived by multiplying the nitrogen content, obtained via the Kjeldahl method, by a factor of 5.75. Oil content was assessed by weight following **AOAC (2000),** and anthocyanin pigments were quantified spectrophotometrically in accordance with **AOAC (2000).**

Data were statistically analyzed, following the method described by **Gomez and Gomez, (1984),** using analysis of variance (ANOVA) at a 5% significance level. Duncan letters are used when displaying the results to make them clearer. CoStat software (Version 6.303, Copyright ,1998-2004) was used.

3. Results

3.1. Growth parameters and leaf chemical traits

Table 2 shows the effects of magnesium sulphate soil addition and foliar application of wood vinegar and seaweed at different rates on the growth parameters of maize during the seasons of 2023 and 2024. The data consistently show highly significant differences (indicated by F test*), highlighting that the treatments applied significantly impacted the growth parameters measured. This is crucial for justifying the efficacy of the applied amendments. The increasing trend in plant height, fresh weight, dry weight, and leaf area with higher doses of $MgSO_4$ suggests a positive effect of magnesium on maize growth. The highest treatment (100 kg fed^{-1}) resulted in the best performance across all measured parameters, indicating that magnesium may alleviate salt stress effects, enhancing nutrient uptake and overall plant vigor. The control treatment (without magnesium) recorded the lowest values for all growth parameters, supporting the hypothesis that magnesium application is beneficial for maize growth in salt-affected soils.

Table 2. Effects of magnesium soil addition and foliar application of stimulants on growth parameters of maize during the seasons of 2023 and 2024.

Treatments	Plant height, cm		Fresh weight, g plant^{-1}		Dry weight, g plant^{-1}		Leaf area, cm^2 plant^{-1}	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor : $MgSO_4$ application								
T_1	293.05c	297.87c	892.93c	902.16c	207.87c	210.70c	817.46c	823.43c
T_2	315.83b	322.64b	960.26b	971.79b	228.19b	232.62b	895.73b	905.98b
T_3	333.75a	340.42a	1098.93a	1116.05a	244.52a	247.79a	950.26a	959.06a
F test	***	***	***	***	***	***	***	***
Sub main : Foliar applications								
F_1	304.46e	308.79e	946.33e	957.18e	219.88e	222.55e	862.55e	872.39e
F_2	311.78d	317.20d	979.33d	990.33d	224.77d	227.62d	879.66d	888.11d
F_3	315.07c	321.00c	986.66c	998.53c	226.88c	231.22c	889.44c	898.11c
F_4	318.26b	325.23b	997.00b	1011.76b	229.89b	233.82b	898.77b	908.62b
F_5	321.48a	329.32a	1010.88a	1025.52a	232.88a	236.66a	908.66a	913.55a
F test	***	***	***	***	***	***	***	***
Interaction (T x F)								
F test	***	***	***	***	***	**	***	***

Means within a row followed by a different letter (s) are statistically different at a 0.05 level
T_1: Control (without soil addition), **T_2:** $MgSO_4$ (50 kg fed^{-1}), **T_3:** $MgSO_4$ (100 kg fed^{-1}), **F_1**: Control (without foliar application), **F_2:** Seaweed (7.5 g L^{-1}), **F_3**: Wood vinegar (2 ml L^{-1}), **F_4:** Seaweed (15 g L^{-1}), **F_5:** Wood vinegar (4 m L^{-1})

Foliar applications of both seaweed and wood vinegar improved maize growth compared to the control. The increase in fresh and dry weights, as well as leaf area, indicates that these biostimulants effectively enhance physiological processes, potentially improving stress tolerance and nutrient utilization. The foliar application of wood vinegar at a rate of 4 m L^{-1} was a superior treatment followed by seaweed treatment at a rate of 15 g L^{-1} then wood vinegar at a rate of 2 m L^{-1} then seaweed treatment at a rate of 7.5 g L^{-1} and lately the control group (without foliar application). The results demonstrate a dose-response effect, particularly for seaweed and wood vinegar applications. For instance, seaweed at 15 g L^{-1} and wood vinegar at 4 ml L^{-1} led to the highest growth metrics, which suggests that optimizing the concentration of these biostimulants is critical for maximizing maize productivity. The interaction between magnesium application and foliar treatments showed that maize plants benefited significantly when both magnesium and biostimulants were used together. This synergistic effect was particularly evident in the higher combinations of magnesium with the optimal concentrations of seaweed and wood vinegar, leading to superior growth responses.

Table 3 illustrates the effects of magnesium sulphate application and foliar treatments with seaweed extracts and wood vinegar on the chemical constituents of maize leaves during the 2023 and 2024 growing summer seasons. Meanwhile, Table 4 shows how these treatments affected the levels of essential nutrients (nitrogen, phosphorus and potassium) in maize leaves over the same period.

Table 3. Effects of magnesium soil addition and foliar application of stimulants on leaf chemical constituents of maize during the seasons of 2023 and 2024 .

Treatments	Chlorophyll a, mg g^{-1} FW		Chlorophyll b, mg g^{-1} FW		Carotene, mg g^{-1} FW	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor : $MgSO_4$ application						
T_1	0.893c	0.932c	0.607c	0.633c	0.538c	0.559c
T_2	0.998b	1.046b	0.665b	0.691b	0.590b	0.614b
T_3	1.112a	1.160a	0.728a	0.762a	0.652a	0.679a
F test	***	***	***	***	***	***
Sub main : Foliar applications						
F_1	0.964e	1.012e	0.644e	0.673e	0.570e	0.596e
F_2	0.981d	1.032d	0.655d	0.684d	0.583d	0.606d
F_3	0.997c	1.047c	0.667c	0.695c	0.594c	0.618c
F_4	1.018b	1.061b	0.678b	0.705b	0.605b	0.630b
F_5	1.045a	1.079a	0.689a	0.720a	0.615a	0.637a
F test	***	***	***	***	***	***
Interaction (T x F)						
F test	***	***	**	***	*	**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level
T_1: Control (without soil addition), **T_2:** $MgSO_4$ (50 kg fed^{-1}), **T_3:** $MgSO_4$ (100 kg fed^{-1}), **F_1**: Control (without foliar application), **F_2:** Seaweed (7.5 g L^{-1}), **F_3**: Wood vinegar (2 ml L^{-1}), **F_4:** Seaweed (15 g L^{-1}), **F_5:** Wood vinegar (4 m L^{-1})

Table 4. Effects of magnesium soil addition and foliar application of stimulants on leaf photosynthetic pigments of maize during the seasons of 2023 and 2024.

Treatments	N,%		P,%		K,%	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor : $MgSO_4$ application						
T_1	2.92c	3.05c	0.320c	0.333c	2.61c	2.70c
T_2	3.40b	3.52b	0.361b	0.377b	3.10b	3.19b
T_3	3.79a	3.94a	0.403a	0.418a	3.47a	3.59a
F test	***	***	***	***	***	***
Sub main : Foliar applications						
F_1	3.17e	3.35e	0.348e	0.361e	2.87e	2.99e
F_2	3.28d	3.44d	0.356d	0.372d	2.98d	3.15d
F_3	3.39c	3.52c	0.362c	0.376c	3.08c	3.17c
F_4	3.49b	3.58b	0.367b	0.384b	3.14b	3.23b
F_5	3.53a	3.64a	0.374a	0.388a	3.23a	3.27a
F test	***	***	***	***	***	***
Interaction (T x F)						
F test	***	**	***	**	***	**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level
T_1: Control (without soil addition), **T_2:** $MgSO_4$ (50 kg fed^{-1}), **T_3:** $MgSO_4$ (100 kg fed^{-1}), **F_1**: Control (without foliar application), **F_2:** Seaweed (7.5 g L^{-1}), **F_3**: Wood vinegar (2 ml L^{-1}), **F_4:** Seaweed (15 g L^{-1}), **F_5:** Wood vinegar (4 m L^{-1})

The results reveal a significant increase in chlorophyll a, b and carotene, as well as concentrations of N, P and K, with higher magnesium doses. The highest values for all traits listed in Tables 3 and 4 were observed with the application of 100 kg fed^{-1}, highlighting the positive effect of magnesium on enhancing maize's photosynthetic ability. Conversely, the control group (without magnesium) displayed significantly lower values, reinforcing the notion that magnesium supplementation improves leaf chemical composition. Foliar applications of seaweed extracts and wood vinegar also had a favorable impact on leaf photosynthetic pigments and nutrient content. Specifically, applying seaweed at 15 g L^{-1} and wood vinegar at 4 mL L^{-1} led to substantial increases in chlorophyll a, b, and carotene levels. Additionally, these foliar treatments improved the nutrient content, with both seaweed and wood vinegar elevating nitrogen, phosphorus, and potassium levels in comparison to the control treatment (without foliar application).The interaction between magnesium sulphate addition and foliar applications resulted in significant synergistic effects on maize leaf quality. For example, combining magnesium sulphate at 100 kg fed^{-1} with foliar treatments of seaweed (15 g L^{-1}) or wood vinegar (4 mL L^{-1}) produced markedly higher leaf photosynthetic pigments and nutrient levels than either treatment alone.

Table 5 illustrates the effects of magnesium sulphate application and foliar treatments using seaweed extracts and wood vinegar on the proline and malondialdehyde (MDA) contents in maize leaves during the 2023 and 2024 growing seasons. The data indicate that the addition of magnesium sulphate significantly influenced proline and MDA levels in maize leaves. Notably, increasing the magnesium application from the control (without magnesium) to 100 kg fed^{-1} resulted in a marked increase in proline content (from 7.63 µg g^{-1} in the control to 10.33 µg g^{-1} in the highest treatment in the first season and from 8.00 µg g^{-1} in the control to 10.86 µg g^{-1} in the second season), while simultaneously reducing MDA levels (from 11.99 µmol g^{-1} in the control to 8.92 µmol g^{-1} with 100 kg fed^{-1} in the first season and from 12.63 µmol g^{-1} in the control to 9.30 µmol g^{-1} with 100 kg fed^{-1} in the second season). This suggests that magnesium sulphate may enhance the plant's stress response by promoting proline accumulation, which is known to function as an osmoprotectant, while also reducing lipid peroxidation as indicated by lower MDA levels. The results for foliar applications show that both seaweed extracts and wood vinegar significantly improved proline and MDA levels across the seasons. For example, in the first season, the application of seaweed at 15 g L^{-1} achieved higher proline levels (9.23 µg g^{-1}) and reduced MDA levels (10.20 µmol g^{-1}), demonstrating the potential of these foliar treatments to enhance leaf quality and stress tolerance. Similarly, wood vinegar at 4 mL L^{-1} produced comparable effects, indicating that both substances can effectively contribute to improving maize resilience against oxidative stress.

Table 5. Effects of magnesium soil addition and foliar application of stimulants on leaf proline and MDA contents of maize during the seasons of 2023 and 2024.

Treatments	Proline, µg.g^{-1} F.W		MDA, µmol.g^{-1} F.W	
	1st season	2nd season	1st season	2nd season
Main factor : $MgSO_4$ application				
T_1	7.63c	8.00c	11.99a	12.63a
T_2	9.00b	9.46b	10.44b	10.87b
T_3	10.33a	10.86a	8.92c	9.30c
F test	***	***	***	***
Sub main : Foliar applications				
F_1	8.52d	8.94e	10.94a	11.61a
F_2	8.79cd	9.22d	10.70b	11.17b
F_3	8.98c	9.44c	10.42c	10.87c
F_4	9.23b	9.69b	10.20d	10.62d
F_5	9.42a	9.90a	9.990e	10.39e
F test	***	***	***	***
Interaction (T x F)				
F test	**	***	***	***

Means within a row followed by a different letter (s) are statistically different at a 0.05 level
T_1: Control (without soil addition), **T_2:** $MgSO_4$ (50 kg fed^{-1}), **T_3:** $MgSO_4$ (100 kg fed^{-1}), **F_1**: Control (without foliar application), **F_2:** Seaweed (7.5 g L^{-1}), **F_3**: Wood vinegar (2 ml L^{-1}), **F_4:** Seaweed (15 g L^{-1}), **F_5:** Wood vinegar (4 m L^{-1})

The interaction between magnesium sulphate and foliar applications resulted in significant synergistic effects on proline and MDA levels. For instance, when magnesium sulphate (100 kg fed^{-1}) was combined with seaweed extracts (15 g L^{-1}), the proline content reached 10.53 µg g^{-1}, demonstrating an additive effect of magnesium and foliar application in enhancing proline levels. Concurrently, MDA levels were minimized (8.69 µmol g^{-1}) under this treatment combination, further illustrating how the combined use of magnesium and foliar stimulants can synergistically improve maize leaf quality.

3.2. Yield and quality parameters

Table 6 presents the effects of magnesium sulphate ($MgSO_4$) soil application and foliar applications of seaweed extracts and wood vinegar on various yield components of maize, including cob length, cob weight, weight of 100 grains, grain yield, biological yield (Fig2) and harvest index across two growing seasons (2023 and 2024).

Table 6. Effects of magnesium soil addition and foliar application of stimulants on yield and its component of maize during the seasons of 2023 and 2024.

Treatments	Cob length, cm		Weight of cob, g		Weight of 100 grain, g	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor : $MgSO_4$ application						
T_1	18.94c	19.34c	192.77c	202.37c	42.93c	43.68c
T_2	22.52b	23.02b	264.38b	277.09b	48.13b	48.89b
T_3	26.50a	27.07a	298.15a	312.74a	49.51a	50.16a
F test	***	***	***	***	***	***
Sub main : Foliar applications						
F_1	21.50e	21.93e	242.26e	253.97e	46.35c	47.09d
F_2	21.95d	22.50d	246.12d	259.10d	46.65bc	47.33c
F_3	22.70c	23.19c	250.69c	264.09c	46.89b	47.56bc
F_4	23.16b	23.67b	257.29b	268.98b	47.14ab	47.83b
F_5	23.69a	24.432a	262.47a	274.21a	47.26a	48.08a
F test	***	***	***	***	***	***
Interaction (T x F)						
F test	***	***	***	***	**	***

Means within a row followed by a different letter (s) are statistically different at a 0.05 level
T_1: Control (without soil addition), **T_2:** $MgSO_4$ (50 kg fed^{-1}), **T_3:** $MgSO_4$ (100 kg fed^{-1}), **F_1**: Control (without foliar application), **F_2:** Seaweed (7.5 g L^{-1}), **F_3**: Wood vinegar (2 ml L^{-1}), **F_4:** Seaweed (15 g L^{-1}), **F_5:** Wood vinegar (4 m L^{-1})

Cont. Table 6.

Treatments	Grain yield, ton ha^{-1}		Biological yield, ton ha^{-1}		Harvest index,%	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor : $MgSO_4$ application						
T_1	7.49c	7.61c	14.32c	14.58c	52.31c	52.20c
T_2	9.05b	9.19b	16.44b	16.69b	55.05b	55.10b
T_3	9.89a	10.03a	17.72a	18.02a	55.82a	55.72a
F test	***	***	***	***	***	***
Sub main : Foliar applications						
F_1	8.46c	8.61e	15.68e	15.90e	53.80a	53.82a
F_2	8.73b	8.75d	15.94d	16.19d	53.84a	53.97a
F_3	8.87ab	8.99c	16.12c	16.35c	54.61a	54.36a
F_4	8.99a	9.16b	16.4b1	16.74b	54.78a	54.65a
F_5	9.00a	9.23a	16.66a	16.96a	54.95a	54.88a
F test	***	***	***	***	NS	NS
Interaction (T x F)						
F test	**	***	***	***	*	*

Means within a row followed by a different letter (s) are statistically different at a 0.05 level
T_1: Control (without soil addition), **T_2:** $MgSO_4$ (50 kg fed^{-1}), **T_3:** $MgSO_4$ (100 kg fed^{-1}), **F_1**: Control (without foliar application), **F_2:** Seaweed (7.5 g L^{-1}), **F_3**: Wood vinegar (2 ml L^{-1}), **F_4:** Seaweed (15 g L^{-1}), **F_5:** Wood vinegar (4 m L^{-1})

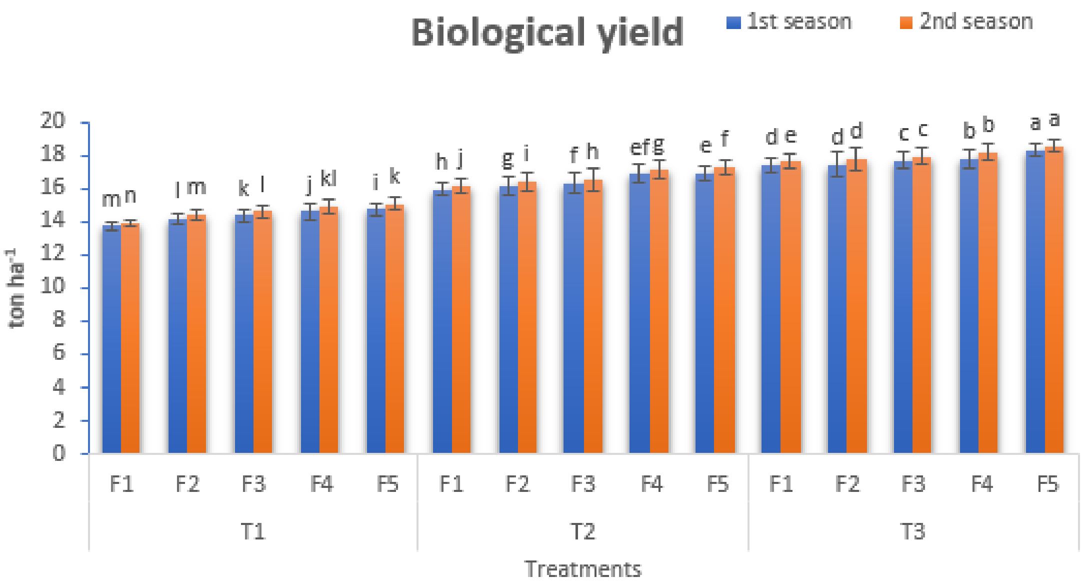

Fig. 2. Effects of magnesium soil addition and foliar application of stimulants on biological yield of maize during the seasons of 2023 and 2024.

T_1: Control (without soil addition), **T_2:** $MgSO_4$ (50 kg fed^{-1}), **T_3:** $MgSO_4$ (100 kg fed^{-1}), **F_1**: Control (without foliar application), **F_2**: Seaweed (7.5 g L^{-1}), **F_3**: Wood vinegar (2 ml L^{-1}), **F_4**: Seaweed (15 g L^{-1}), **F_5**: Wood vinegar (4 m L^{-1})

The application of $MgSO_4$ significantly increased cob length, with the highest dose (100 kg fed^{-1}) resulting in the longest cobs (26.50 cm and 27.07 cm in the first and second seasons, respectively). This indicates that magnesium plays a crucial role in enhancing cob development. A similar trend was observed for cob weight, where the highest $MgSO_4$ application produced the heaviest cobs (298.15 g and 312.74 g). This reflects the positive impact of magnesium on maize productivity, likely due to improved nutrient uptake and photosynthetic efficiency. The weight of 100 grains also increased significantly with higher $MgSO_4$ doses, suggesting that magnesium contributes to better grain filling and overall seed quality. Both grain and biological yields were substantially higher with increased $MgSO_4$ application, with the maximum yield observed at 100 kg fed^{-1} (9.89 ton ha^{-1} and 10.03 ton ha^{-1} for grain yield; 17.72 ton ha^{-1} and 18.02 ton ha^{-1} for biological yield) during the both growing seasons, respectively. This highlights the importance of adequate magnesium in achieving optimal yield in maize. Although the harvest index showed significant improvement with $MgSO_4$ application, the increase was relatively modest compared to other parameters, indicating that magnesium's effect is more pronounced on overall biomass rather than the partitioning of biomass into grains.

The foliar application of seaweed extracts and wood vinegar led to significant increases in cob length, cob weight, and grain weight. The most effective treatments were seaweed at 15 g L^{-1} and wood vinegar at 4 mL L^{-1}, suggesting that these bio-stimulants can enhance maize growth and yield components, possibly by improving plant health and stress resistance. Foliar applications also boosted both grain and biological yields. The highest grain yields were observed with wood vinegar at 4 mL L^{-1}, indicating its potential as a potent bio-stimulant. However, the effect on the harvest index was not statistically significant, suggesting that while foliar applications increase yield, they do not necessarily alter the balance between grain and total biomass production.The interaction between $MgSO_4$ and foliar applications was highly significant for yield and all its components. The combination of 100 kg fed^{-1} $MgSO_4$ and wood vinegar at 4 mL L^{-1} produced the best results, with maximum values. This synergy indicates that the combined use of soil-applied magnesium and foliar bio-stimulants can significantly enhance maize productivity.

Data in Tables 7 and 8 highlight the significant effects of magnesium soil additions and foliar applications on the nutrient concentrations and nutrient uptake of maize, respectively, during the 2023 and 2024 summer seasons. The application of magnesium sulphate ($MgSO_4$) had a pronounced impact on the concentration of nitrogen (N), phosphorus (P) and potassium (K) in maize grains. Increasing the $MgSO_4$ application from 50 kg to 100 kg fed^{-1} resulted in a significant rise in NPK concentrations across both seasons. For instance, nitrogen concentrations increased from 1.65% in the control to 2.37% in the first season and dramatically from 1.75 to 4.47% in the second season with 100 kg fed^{-1} $MgSO_4$ application. Similarly, phosphorus and potassium concentrations also followed this upward trend with increased $MgSO_4$ application. This suggests that magnesium not only supports better nutrient uptake but also enhances the overall nutrient profile in maize grains (Table 7).

Foliar applications further improved NPK concentrations, particularly at higher concentrations of seaweed (15 g L^{-1}) and wood vinegar (4 ml L^{-1}). These treatments likely provided additional nutrients or stimulated physiological processes that enhanced nutrient absorption and assimilation in the plants (Table 7). Correspondingly, nutrient uptake (expressed in kg fed^{-1}) also increased with both $MgSO_4$ soil addition and foliar applications (Table 8). The highest nutrient uptake values were observed with the combined application of 100 kg $fed^{-1}$$MgSO_4$ and the most concentrated foliar treatments. For example, nitrogen uptake peaked at 110.38 kg fed^{-1} in the second season under 100 kg fed^{-1} $MgSO_4$ and 4 ml L^{-1} wood vinegar application. This indicates that the combined use of magnesium soil amendments and foliar stimulants can significantly enhance the efficiency of nutrient use in maize, leading to higher overall nutrient uptake by the plants. The interaction effects observed in both nutrient concentrations and uptake emphasize the synergistic relationship between soil and foliar treatments.

Table 7. Effects of magnesium soil addition and foliar application of stimulants on grain nutrient concentrations (NPK) of maize during the seasons of 2023 and 2024 .

Treatments	N,%		P,%		K,%	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor : $MgSO_4$ application						
T_1	1.65c	1.75c	0.224c	0.232c	1.36c	1.45c
T_2	2.08b	2.16b	0.255b	0.264b	1.93b	2.03b
T_3	2.37a	2.47a	0.282a	0.295a	2.17a	2.28a
F test	***	***	***	***	***	***
Sub main : Foliar applications						
F_1	1.85e	1.98e	0.244e	0.255e	1.71e	1.83e
F_2	1.98d	2.07d	0.249d	0.259d	1.77d	1.88d
F_3	2.05c	2.14c	0.255c	0.263c	1.82c	1.91c
F_4	2.11b	2.19b	0.260b	0.267b	1.87b	1.97b
F_5	2.18a	2.27a	0.263a	0.272a	1.93a	2.03a
F test	***	***	***	***	***	***
Interaction (T x F)						
F test	***	***	***	**	**	**

Table 8. Effects of magnesium soil addition and foliar application of stimulants on grain nutrient uptake (NPK) of maize during the seasons of 2023 and 2024.

Treatments	N, Kg fed^{-1}		P, Kg fed^{-1}		K, Kg fed^{-1}	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor : $MgSO_4$ application						
T_1	51.74a	56.01a	7.02a	7.37a	42.54a	46.33a
T_2	78.56b	82.99b	9.64b	10.12b	73.08b	78.09b
T_3	97.98a	103.6a	11.66a	12.33a	89.65a	95.60a
F test	***	***	***	***	***	***
Sub main : Foliar applications						
F_1	66.88e	72.76e	8.72e	9.28e	62.09e	67.40e
F_2	73.37d	77.02d	9.16d	9.59d	65.85d	70.28d
F_3	77.11c	81.45c	9.53c	9.98c	68.87c	73.07c
F_4	80.37b	84.65b	9.82b	10.28b	71.49b	76.48b
F_5	82.73a	88.51a	9.97a	10.59a	73.81a	79.46a
F test	***	***	***	***	***	***
Interaction (T x F)						
F test	**	***	**	**	**	**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level
T_1: Control (without soil addition), **T_2:** $MgSO_4$ (50 kg fed^{-1}), **T_3:** $MgSO_4$ (100 kg fed^{-1}), **F_1**: Control (without foliar application), **F_2:** Seaweed (7.5 g L^{-1}), **F_3**: Wood vinegar (2 ml L^{-1}), **F_4:** Seaweed (15 g L^{-1}), **F_5:** Wood vinegar (4 m L^{-1})

Table 9 summarizes the influence of different levels of magnesium sulphate ($MgSO_4$) application and various foliar treatments on the protein, carbohydrate, oil and anthocyanin content of maize grains across two growing seasons. The application of $MgSO_4$ significantly increased the protein, carbohydrate, oil and anthocyanin contents in maize grains across both seasons. The highest values were observed with the 100 kg fed^{-1} application rate, showing a marked improvement compared to the control. Foliar applications, particularly higher concentrations of seaweed (15 g L^{-1}) and wood vinegar (4 ml L^{-1}), significantly increased protein content in maize grains. These treatments consistently outperformed the control across both seasons.

Table 9. Effects of magnesium soil addition and foliar application of stimulants on grain quality traits of maize during the seasons of 2023 and 2024 .

Treatments	Protein, %		Carbohydrates,%		Oil, %		Anthocyanin, mg $100g^{-1}$	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor : $MgSO_4$ application								
T_1	9.49c	10.10c	66.30c	67.72c	4.21c	4.38c	24.63c	24.86c
T_2	11.88b	12.44b	69.60b	71.38b	6.08b	6.11b	27.31b	27.64b
T_3	13.64a	14.24a	72.06a	74.42a	6.45a	6.73a	29.72a	30.09a
F test	***	***	***	***	***	***	***	***
Sub main : Foliar applications								
F_1	10.61e	11.40e	68.75e	70.31e	5.23e	5.50e	26.14e	26.44e
F_2	11.38d	11.89d	69.14d	70.98d	5.53d	5.60d	26.84d	27.15d
F_3	11.80c	12.32c	69.46c	71.09c	5.64c	5.71c	27.30c	27.58c
F_4	12.05b	12.61b	69.54b	71.70b	5.74b	5.88b	27.73b	28.05b
F_5	12.53a	13.09a	69.72a	71.79a	5.76a	6.00a	28.10a	28.43a
F test	***	***	***	***	***	***	***	***
Interaction (T x F)								
F test	***	***	***	***	***	***	**	***

Means within a row followed by a different letter (s) are statistically different at a 0.05 level
T_1: Control (without soil addition), **T_2:** $MgSO_4$ (50 kg fed^{-1}), **T_3:** $MgSO_4$ (100 kg fed^{-1}), **F_1**: Control (without foliar application), **F_2:** Seaweed (7.5 g L^{-1}), **F_3**: Wood vinegar (2 ml L^{-1}), **F_4:** Seaweed (15 g L^{-1}), **F_5:** Wood vinegar (4 m L^{-1})

The application of $MgSO_4$ showed a notable improvement in protein percentage, with the highest rates observed at 100 kg fed^{-1}, achieving 13.64% and 14.24% in the first and second seasons, respectively, compared to the control, which recorded the lowest values (9.49% and 10.10%in both studied seasons, respectively). This suggests a positive role of magnesium in enhancing nitrogen metabolism and protein synthesis. Similarly, foliar applications showed a significant effect on protein content. Wood vinegar at 4 mL L^{-1} produced the highest protein percentages (12.53% and 13.09% across the two seasons), followed by seaweed extract at 15 g L^{-1}, while the control consistently exhibited the lowest values. The interaction between $MgSO_4$ application and foliar treatments further amplified the results. The combination of 100 kg fed^{-1} $MgSO_4$ with wood vinegar (4 mL L^{-1}) resulted in the highest protein content across both seasons (14.26% and 14.95%). Carbohydrate content was significantly improved by foliar applications, with the wood vinegar (4 ml L^{-1}) treatment yielding the highest carbohydrate percentage. Foliar applications, especially at higher rates, led to significant increases in oil content, with wood vinegar (4 ml L^{-1}) and seaweed (15 g L^{-1}) being particularly effective. The anthocyanin content was also significantly enhanced by foliar treatments, with the wood vinegar (4 ml L^{-1}) and seaweed (15 g L^{-1}) applications showing the highest anthocyanin levels.

4. Discussion

According to the results obtained, it can be noted that the studied variety has a greater ability to tolerate salt stress than the varieties available in the Egyptian market. This was shown in growth and productivity criteria as well as oxidation indicators, most notably malondialdehyde and proline. The obtained results may be attributed to that magnesium is a crucial element in plant physiology, serving as the central atom in the chlorophyll molecule, which is essential for photosynthesis. Under salt affected soils, the availability of magnesium can help stabilize the structure of chloroplasts, ensuring efficient photosynthesis even under stress (**Farooq *et al.* 2015)**. This increased photosynthetic efficiency leads to improved growth and higher accumulation of important chemical components, such as proteins, carbohydrates, and oils in maize grains. Magnesium also may have played a vital role in the activation of various enzymes that are involved in the plant's defense mechanisms against oxidative stress, which is common in salt affected soils. By enhancing antioxidant enzyme activities, magnesium helps mitigate the harmful effects of reactive oxygen species (ROS), leading to higher anthocyanin content, which is a key antioxidant compound (**Xuan *et al.* 2022)**.

The application of $MgSO_4$ not only provided magnesium but also sulfur, which is crucial for protein synthesis and enzyme activation. Sulfur, provided in the form of sulphates like $MgSO_4$, is essential for the synthesis of amino acids, proteins, and certain vitamins, all of which are vital for maize plant growth and development. Sulphate ions help in the formation of disulfide bonds in proteins, enhancing their stability and functionality. In salt affected soils, sulfur can improve nutrient uptake and balance, leading to better growth and higher content of beneficial compounds in maize grains. Moreover, sulphates may also lower soil pH, which may enhance the availability of other essential nutrients in salt affected soils. This contributes to the observed improvements in carbohydrate and oil content in the treated maize plants (**Yousif *et al.* 2023; Soliman *et al.* 2024)**.

The benefits observed from using wood vinegar can be attributed to its rich content of organic acids, phenolic compounds, and other bioactive molecules that promote plant growth. Wood vinegar's potent antioxidant and antimicrobial properties help shield plants from pathogens and oxidative stress, which is particularly beneficial under challenging conditions such as salt affected soils. This protective effect likely contributed to the significant improvements in grain quality traits, including protein, carbohydrate, oil, and anthocyanin content in maize **(Akley *et al.* 2023**). The growth-enhancing effects of wood vinegar were evident in the overall improvement of maize grain quality traits. Specifically, applying wood vinegar at a concentration of 4 ml L^{-1} led to notable increases in protein and carbohydrate content, as well as oil and anthocyanin levels, when compared to untreated controls. This indicates that wood vinegar not only supports plant survival under salt affected soil but also enhances their growth and productivity, leading to higher-quality yields **(El-Fawy *et al.* 2024).**

Similarly, the improvements seen with seaweed extracts can be attributed to the presence of bioactive compounds that enhance photosynthesis, nutrient uptake, and stress tolerance. Seaweed extracts are rich in plant hormones (such as auxins, cytokinins, and gibberellins), vitamins, and trace elements that act as biostimulants. These compounds stimulate cell division, elongation, and differentiation, which result in improved plant growth and increased yields. Additionally, seaweed extracts boost a plant's ability to withstand abiotic stresses like salinity by enhancing water retention, increasing antioxidant activity by increasing proline production which responsible for promoting ROS scavenging **(El-Nwehy *et al.* 2021),** and stabilizing cell membranes. This leads to better grain yield and quality **(Faiyad *et al.* 2024; Hussein *et al.* 2021; Fatima *et al.* 2024).**

5. Conclusion

Based on the results of this research, it can be concluded that adding magnesium sulphate to soil at rates ranging from 50 to 100 kg/acre, along with foliar spraying of seaweed extract or wood vinegar, significantly improves the growth and grain quality of maize grown on salt-affected soils. The synergistic effects of magnesium and sulfur from magnesium sulphate fertilizer, along with the bioactive compounds in seaweed and wood vinegar, lead to increased levels of protein, carbohydrates, oil, and anthocyanins in maize grains. Therefore, this research recommends using a mixture of magnesium sulphate at a rate of 100 kg/acre, along with foliar spraying of seaweed extract (15 g/L) or wood vinegar (4 ml/L), for maize cultivation, especially under salt-affected soil conditions. This approach improves growth, productivity, and grain quality, providing an effective strategy for addressing the challenges posed by saline environments.

Conflicts of interest: The authors have declared that no competing interests exist.

Formatting of funding sources: The research was funded by the personal efforts of the authors.

6. References

Ábrahám, E., Hourton-Cabassa, C., Erdei, L., & Szabados, L. (2010). Methods for determination of proline in plants. Plant stress tolerance: methods and protocols, 317-331.

Akley, E. K., Ampim, P. A., Obeng, E., Sanyare, S., Yevu, M., Owusu Danquah, E., ... & Seidu, A. F. (2023). Wood vinegar promotes soil health and the productivity of cowpea. Agronomy, 13(10), 2497.

AOAC, (2000). ˝Official Methods of Analysis ̏. 18th Ed. Association of Official Analytical Chemists, Inc., Gaithersburg, MD, Method 04.

Behera, S. K., Suresh, K., Shukla, A. K., Kamireddy, M., Mathur, R. K., & Majumdar, K. (2021). Soil and leaf potassium, calcium and magnesium in oil palm (*Elaeis guineensis* Jacq.) plantations grown on three different soils of India: Status, stoichiometry and relations. *Industrial Crops and Products*, *168*, 113589.

Elbaalawy, A. M., Tantawy, M. F., Abd Elhafez, E., & Nada, W. M. (2023). Sulphur compost properties and its amelioration effect on salt affected soil characteristics and productivity. Egyptian Journal of Soil Science, 63(3), 339-354.

El-Fawy, M. M., Saeed, A. S., Abou-Shlell, M. K., Soliman, M. A., Ali, E. F., Issa, A. A., ... & El-Nagar, A. S. (2024). Effectiveness of biochar and wood vinegar from guava trees in controlling Fusarium verticillioides and enhancing growth and anatomical traits of maize (Zea mays L.). Journal of Plant Diseases and Protection, 1-15.

El-Fouly, M. M., Rezk, A. I., Nofal, O. A., & Abou El-Nour, E. A. A. (2010). Depletion of magnesium in Egyptian soils, its content in crops and estimated needs. Afr. J. Agric. Res, 5, 1060-1067.

El-Nwehy, S. S.; Rezk, A. and El-Nasharty, A. B. (2021). Role of bio-stimulants in crop production under salinity stress. A review. Middle East J. Agric. Res., 10(1): 188-206.

El-Sherpiny, M.A., Baddour, A.G, El-Kafrawy, M.M., & Yousif, E. E. (2023). Evaluating the response of peanuts plant irrigated with agricultural drainage water to organic fertilization and foliar application of magnesium and selenium, along with soil property assessment. Egyptian Journal of Soil Science, 63(4), 621-639.

Elsonbaty,A.,& El-Sherpiny,M.A. (2024). Improving the yield and quality of faba bean grown in alkaline soils using agricultural gypsum, organic fertilizers and cobalt. Egyptian Journal of Soil Science, 64(3), 1285 – 1303.

Faiyad, R. M. N., & AbdEL-Azeiz, E. H. (2024). Mitigation the deleterious effect of salinity on faba bean by cobalt and bio-stimulants. Egyptian Journal of Soil Science, 64(1), 181-192.

Farid, I. M., El-Shinawy, R., Elhussiny, O., Abbas, H., Abbas, M. H., & Bassouny, M. A. (2023). Phosphorus and micronutrient interactions in soil and their impacts on maize growth. Egyptian Journal of Soil Science, 63(4).

Farooq, M., Hussain, M., Wakeel, A., & Siddique, K. H. (2015). Salt stress in maize: effects, resistance mechanisms, and management. A review. Agronomy for Sustainable Development, 35, 461-481.

Fatima, M. M., & Al-Yasari, M. N. H. (2024). Maize response to mineral fertilizers and seaweed extract for growth and yield-related traits. Sabrao Journal of Breeding & Genetics, 56(4).

Gomez, K. A., & Gomez, A.A (1984). "Statistical Procedures for Agricultural Research". John Wiley and Sons, Inc., New York.pp:680.

Hussein, M. H., Eltanahy, E., Al Bakry, A. F., Elsafty, N., & Elshamy, M. M. (2021). Seaweed extracts as prospective plant growth bio-stimulant and salinity stress alleviator for Vigna sinensis and Zea mays. Journal of Applied Phycology, 33, 1273-1291.

Jaiswal, L. K., Singh, P., Singh, R. K., Nayak, T., Tripathi, Y. N., Upadhyay, R. S., & Gupta, A. (2021). Effects of salt stress on nutrient cycle and uptake of crop plants. Physiology of salt stress in plants: perception, signalling, omics and tolerance mechanism, 129-153.

Peterburgski, A. V. (1968)."Handbook of Agronomic Chemistry". Kolos Publishing House, Moscow, (in Russian, pp. 29-86).

Porra, R. J., Thompson, W. A., & Kriedemann, P. E. (1989). Determination of accurate extinction coefficients and simultaneous equations for assaying chlorophylls a and b extracted with four different solvents: verification of the concentration of chlorophyll standards by atomic absorption spectroscopy. Biochimica et Biophysica Acta (BBA)-Bioenergetics, 975(3), 384-394.

Rai, H. (1973). Methods involving the determination of photosynthetic pigments using spectrophotometry: With 4 figures and 9 tables in the text. Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen, 18(3), 1864-1875.

Soliman, M. A., Elsherpiny, M. A., & Elmahdy, S. (2024). Maximizing canola productivity as a promising oil crop in the Egyptian agricultural strategy: A focus on organic and beneficial elements fertilization. Egyptian Journal of Soil Science, 64(2), 397-409.

Tandon, H. L. S. (2005). Methods of analysis of soils, plants, waters, fertilisers & organic manures. Fertilizer Development and Consultation Organisation.

Tisdale, S. L., Nelson, W. L., & Beaton, J. D. (1985). Soil fertility and fertilizers (pp. 754-pp).

Valenzuela, A. (1991). The biological significance of malondialdehyde determination in the assessment of tissue oxidative stress. Life sciences, 48(4), 301-309.

Walinga, I., Van Der Lee, J. J., Houba, V. J., Van Vark, W. and Novozamsky, I. (2013). Plant analysis manual. Springer Science & Business Media.

Xuan, T. D., Huong, C. T., Quan, N. V., Anh, L. H., Khanh, T. D., & Rayee, R. (2022). Improvement of salinity tolerance in rice seedlings by exogenous magnesium sulphate application. Soil Systems, 6(3), 69.

Yousif,E.E., Faiyad, R.M.N ., & Abd El-Azeiz, E.H (2023). Effect of sulfur, boron, zinc and iron on canola under salt affected soils. Egyptian Journal of Soil Science, 63(4), 475-487.