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Effect of Zeolite and Seaweed Extract on Soil Properties and Morphological Traits of Rosa Damascena for Environmentally Sustainable Production

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ABSTRACT

This study investigates the effects of natural zeolite and seaweed extract (SWE) on soil properties and morphological traits of Rosa damascena grown in Zemij soil under greenhouse conditions. Zeolite was applied at concentrations of 0, 5, and 10 mg L^{-1}, while SWE was foliar-applied at 0, 10, and 30 mL L^{-1} using a randomized complete block design. The results showed that SWE significantly improved plant height, number of leaves, lateral shoots, leaf area, and both shoot and root dry weights, with the most notable effects at 30 mL L^{-1}. Although zeolite had a limited individual impact, its interaction with SWE-particularly at 5 mg L^{-1}-led to synergistic improvements in root growth. From an environmental perspective, the findings suggest that both zeolite and SWE can serve as sustainable biostimulants, reducing dependence on chemical fertilizers. This approach contributes to improving soil fertility and resilience against degradation, while minimizing environmental pollution commonly associated with conventional agricultural inputs. The use of these natural amendments in low-fertility soils offers an environmentally friendly and economically viable option for sustainable ornamental plant production, particularly for high-value species like Rosa

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damascena. These findings support using zeolite and seaweed extract as natural biostimulants to improve plant growth and soil quality, particularly in low-fertility soils. Further research should explore their effects on other crops and assess long-term impacts on soil fertility, water efficiency, and environmental sustainability, offering a viable alternative to chemical fertilizers.

Keywords: Seaweed Extract; Zeolite; Zemij Soils; Rosa damascena; Vegetative Growth

1. Introduction

Rosa damascena is one of the most important ornamental and aromatic plants, which has valuable application. It is widely used in the perfume, cosmetics and pharmaceutical industries worldwide as well as is capable of being a source of numerous active substances [1,2]. It is considered as a commercial valuable species and is widely grown in many countries such as Turkey, Bulgaria, Iran, Morocco and Egypt. The oil that is produced from its flowers carries a high market price, due to the unique quality and multi-derivates for which it can be used [3,4]. The growth and yield of (Rosa damascena) are affected by variety of agricultural and environmental factors under cultivation. In particular Zemij soils of Iraq has lack of competition, low nutrient levels and minimization of water-soil interactions which reduces the plant growth and yield. Soil formation suit agriculture is really founded upon the principles of physical and chemical soil amelioration. These goals can be accomplished by the application of natural and organic soil modifications that promote the ability of nutrients, along with the availability of nutrients [5].

Zeolite is a porous crystalline mineral having a high cation exchange capacity (CEC), takes up and retains major nutrients such as potassium, calcium, ammonium, and magnesium, and slowly releases them as per the plant's requirement [6]. Zeolite is a good example of such a change; a natural mineral is used to maintain nutrients in agriculture on a large scale and to improve the soil structure [7]. The zeolite also provides more permeability to the soil, increases the ability to catch the water, adjusts soil pH, and forms a favorable rhizosphere environment (Rhizosphere is a term that describes the region of soil that is directly influenced by plant roots and plays a vital role in interactions between plants and soil microorganisms), and therefore reduces the leaching loss of nutrients [8]. Similarly, marine algae extract SWE is also considered a powerful natural biostimulant. SWE has a wide range of bioactive substances in shapes such as auxin and cytokine in the SWE, such as polymers, beets, amino acids, and plant hormones [9]. SWE induces soil that enhances root growth, microbial activity in the rhizosphere, and nutritional absorption, thus having the plant strength, flowers, and biomass outcomes by Hassan and Ati [10]. Recent studies have highlighted the canalization of zeolite and maritime algae extract combinations in the repetition of Zemij soils, such as zeolite soil relapse. While Zeolite improves the physical and chemical nature of the earth, the SWE plant optimizes physiology. They are a viable way to replace the use of traditional fertilizers, the soil fertility barrier [11,12]. The complementary interaction theory between seaweed extract and zeolite postulates that the combination of the extract's bioactive compounds (such as amino acids and plant hormones) and the physical properties of zeolite (such as cation exchange capacity and water-holding capacity) enhances soil fertility by stimulating microorganisms and improving nutrient availability. This synergism effect leads an improvement of water and nutrient use efficiency in soils, and ultimately a promotion of plant growth and yield [13,14].

The current study aims to evaluate the combined effect of zeolite and seaweed extract on some physical and chemical properties of Zemij soil and morphological traits of *Rosa damascena* under greenhouse conditions.

2. Materials and Methods

The experiment was conducted at the Al-Diwaniyah Municipality Nursery under a green shade house with 25% light filtration using green saran, starting on October 1, 2024. This work was conducted to compare the effects of natural zeolite and seaweed extract application on soil properties and morphological developmental characteristics of Rosa damascena. Results and discussion **Table 1** shows the results of soil texture analysis that showed a sandy-loam type soil having sand content of 780 g kg^{-1}, while silt and clay contents were 108 and 112 g kg^{-1} respectively. This soil type tends to be well drained but has low water and nutrient availability, which may restrict the growth of perennial plants.

The pH of the soil was recorded as 7.20, neutral in nature and supportive for plant growth with high nutrient availability. Electrical conductivity (EC) was found to be 2.20 ds m^{-1} showing non sticky and safe soil condition [15]. The levels of available N, P and K in sandy loam soil were 250, 180 and 100 mg kg^{-1} respectively. The total content of calcium carbonate ($CaCO_3$), which may act in a limiting way the availability on micronutrients such as Fe, Zn and Mn, can be measured by 106 g kg^{-1} of the soil. Organic matter was 18 g kg^{-1}, a reasonable content for the study that could be increased by means of chemical or organic amendments to increase water storage and microbial activity [16].

Seedlings were first planted in plastic seedling trays (55 × 28 cm) with peat moss. After reaching 4–5 cm and two true leaves, the seedlings were transplanted on November 15, 2024 into plastic pots (25 cm diameter × 24 cm high) with one plant per pot. The potting substrate was made of 5 kg alluvial Zemij soil (2:1 ratio)/peat moss mixture. The experiment was based on two factors:

- Factor A: Application of zeolite mineral at three concentrations: 0, 5, and 10 mg L^{-1}
- Factor B: Foliar spray of seaweed extract at three concentrations: 0, 10, and 30 mL L^{-1}

The first application of both zeolite and seaweed extract was performed on November 22, 2024, followed by a second application 21 days later.

The experiment followed a two-factor Randomized Complete Block Design (RCBD) with three replicates, as described by Al-Rawi and Khalaf [17]. Each replicate contained nine treatment combinations (3 × 3), and each treatment unit consisted of three pots, totaling 81 pots for the entire experiment. The data were analyzed using ANOVA (analysis). The treatment agents were compared to the least significant difference (LSD) test at the significance level of $p \leq 0.05$, which was held using the GenStat software version 12.1, VSN International [18]. The experimental layout is illustrated in **Figure 1**.

2.1. Treatment Layout in the Field (RCBD Design)

The treatment design is shown in the following **Table 2**.

Table 1. Selected Physical and Chemical Properties of the Soil.

Property	Value	Unit
Soil pH	7.20	
Electrical conductivity (EC)	2.20	ds m^{-1}
Calcium (Ca)	250	mg kg^{-1}
Magnesium (Mg)	180	mg kg^{-1}
Sodium (Na)	50	mg kg^{-1}
Potassium (K)	100	mg kg^{-1}
Calcium carbonate ($CaCO_3$)	106	mg kg^{-1}
Organic matter	18	mg kg^{-1}
Soil texture	Sandy loam	
– Sand	780	g kg^{-1}
– Silt	108	g kg^{-1}
– Clay	112	$g \cdot kg^{-1}$

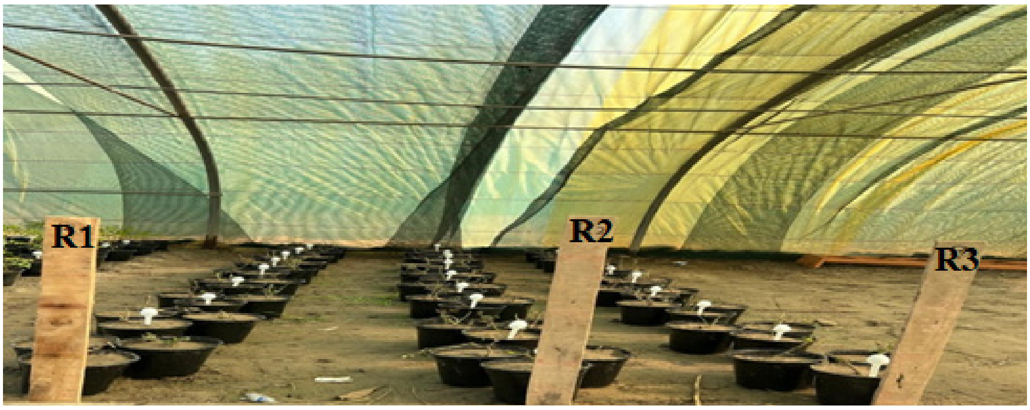

Figure 1. This image shows the arrangement of pots across three replicates (R1, R2, R3) following a two-factor Randomized Complete Block Design (RCBD). Each replicate contained nine treatment combinations with three pots per treatment.

Table 2. Randomized treatments within replicates (R1, R2, R3), coded as (Zeolite mg/L, Seaweed extract mL/L).

Row	R1	R2	R3
1	T2 (0, 10)	T4 (5, 0)	T3 (0, 30)
2	T4 (5, 0)	T3 (0, 30)	T8 (10, 10)
3	T7 (10, 0)	T2 (0, 10)	T1 (0, 0)
4	T5 (5, 10)	T8 (10, 10)	T9 (10, 30)
5	T1 (0, 0)	T6 (5, 30)	T3 (0, 30)
6	T6 (5, 30)	T1 (0, 0)	T3 (0, 30)
7	T8 (10, 10)	T9 (10, 30)	T4 (5, 0)
8	T9 (10, 30)	T5 (5, 10)	T2 (0, 10)
9	T3 (0, 30)	T7 (10, 0)	T5 (5, 10)

2.2. Physical and Chemical Properties Analysis

Soil texture was determined using the international pipette method described by Pansu and Gautheyrou [19]. Soil reaction (pH) was measured in a 1:1 soil-to-water extract using a pH meter, and EC was determined in the same 1:1 soil extract using an EC meter, according to the method described [20]. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) were measured in clay extracts, following the process described by Richards [21], it was determined by titration using Na-EDTA. Meanwhile, sodium (Na^{+}) and potassium (K^{+}) concentrations were measured using a flame photometer according to the methods mentioned page [22]. Organic matter was measured by the wet oxidation method using potassium dichromate, as described by Walkley and Black [23]. Total carbonates in the soil were measured using the calcimeter method according to Hesse [24].

2.3. Plant Growth Parameters Analysis

Plant height was measured using a measuring tape from the soil surface in the pot to the apex of the vegetative shoot. All plants in each treatment unit were measured at the flowering stage, and the average value per treatment was calculated. The total number of leaves was counted per plant for each treatment unit, and the average was calculated accordingly. Branches per plant were counted, and mean values were calculated for each treatment. Leaf area was estimated using the method adopted by O'Neal et al. [25]. Three fully expanded leaves per plant were scanned using a flatbed scanner, and the images were analyzed using Digitizer software on a computer. At the end of the experiment, the plants were carefully cut and separated into the shoots and root systems on the earth's surface. The shoot was placed in a perforated paper bag, dried in the air in a well-ventilated room, and later oven-dried at 45°C until a constant weight was achieved. The roots were washed gently to remove the soil and then kept at the same temperature as the oven after drying in a perforated bag and air for 10 days. The final weight for both shoots and roots was recorded using an accurate digital balance, and the average dry weight per treatment was calculated. All drought and weight procedures were kept in the laboratory for agriculture [26].

3. Results and Discussion

3.1. Growth Indicators Plant Height (cm)

The results in **Table 3** and **Figure 2** have been presented to show that the application of the Marine Algae Extracts (SWE) greatly improved the height of the pink Rosa damascena plant, especially in the highest tested concentration of 30 mL L^{-1}. The effect that promotes this development is attributed to the presence of bioactive compounds in seaweed extracts, which increase cell growth, chlorophyll synthesis, and general vegetation development [27,28]. The height of the highest plants was recorded in the joint treatment of 30 mL L^{-1} SWE + 5 mg L^{-1} zeolite, indicating a positive CO interaction between organic and mineral inputs. This synergism is likely to increase physical and hormonal activity from seaweed extracts, while zeolite improves soil composition, retention of nutrients, and water-holding capacity, which optimizes the root out [29]. **Figure 2** shows this synergistic tendency: At all levels of zeolite, the (SWE) concentration increases from 0 to 30 mL, leading to a marked and steady increase in the height of the plant, with the most remarkable spike at the 5 mg L^{-1} zeolite level.

Table 3. Effect of Zeolite Application, Seaweed Extract Foliar Spray, and Their Interaction on Plant Height (cm) of *Rosa damascena.*

Treatments		Seaweed Extract (SWE) mL L^{-1}			The Average Effect of the Zeolite Mineral
		0	10	30	
Zeolite mineral mg L^{-1}	0	14.00	18.33	19.00	17.11
	5	12.67	16.33	20.00	16.33
	10	14.00	17.67	19.67	17.11
Average effect of Seaweed extract (SWE)		13.56	17.44	19.56	
L.S.D 0.05		Zeolite mineral	1.800		
		Seaweed extract (SWE)	1.800		
		Interference	3.118		

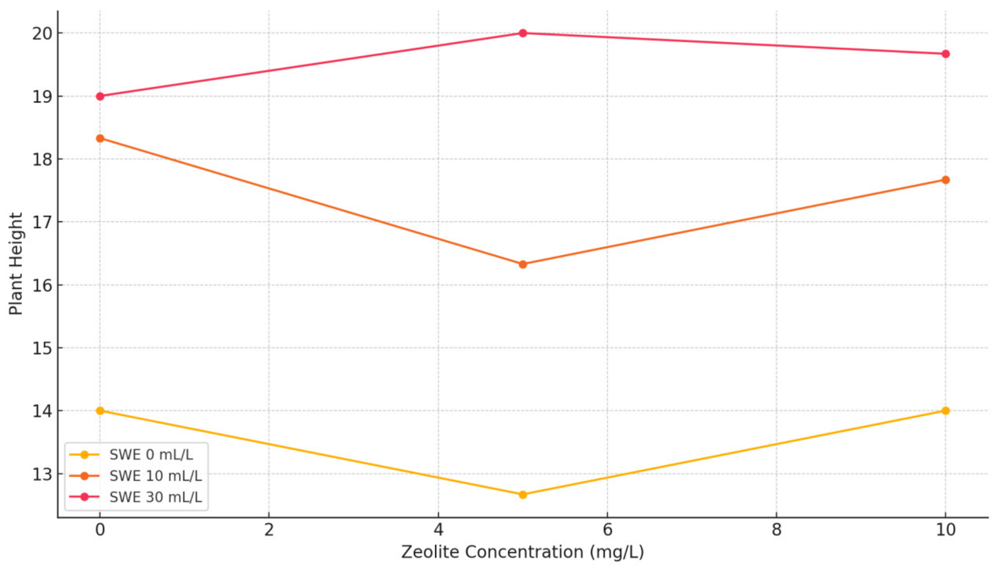

Figure 2. Effect of Different Concentrations of Seaweed Extract (SWE) and Zeolite on Plant Height of Rosa damascena.

3.2. Number of Leaves (Leaves Plant−1)

Results in **Table 4** and illustrated in **Figure 3** suggest that SWE has increased the number of leaves in Rosa damascena plants sharply. The average blade number increased from 14.44 to 22.00 with the SWE concentration from 0 to 30 mL L-1. This trend indicates a strong dose-response ratio, where high concentrations of SWE provide more nutrients and bioactive compounds that encourage leaf growth. Interestingly, the most recorded figure 23.33 leaves plant-1 was found in treatment with 0 mg L^{-1} zeolite and 30 mL L^{-1} SWE, suggesting that SWE is very effective at promoting vegetation development alone. By mixing zeolites with SWE, this value is slightly reduced when both changes are used for leaf numbers at the same time, affecting a potential counter-work or slim effect. This conclusion is statistically supported by LSD values (2235 for single factors and 4027 for interaction), which indicate that only the SWE factor and its interaction achieved significant differences. Zeolite mineral had no obvious effect, as the difference in concentrations was not significant. These findings match those reported by Kularathne et al. and Hassan et al. [30,31]. **Figure 3** clearly shows this pattern, which reflects the extended increase in the number of leaves with increasing SWE concentration, especially below 0 mg L^{-1} zeolite.

Table 4. Effect of Zeolite Application, Seaweed Extract Foliar Spray, and Their Interaction on the Number of Leaves per Plant (Leaves plant−1) of Miniature Rose *Rosa damascena.*

Treatments		**Seaweed Extract (SWE) mL L^{-1}**			**The Average Effect of the Zeolite Mineral**
		0	10	30	
Zeolite mineral mg L^{-1}	0	15.67	18.00	23.33	19.00
	5	13.67	16.33	21.67	17.22
	10	14.00	18.67	21.00	17.89
Average effect of Seaweed extract (SWE)		14.44	17.67	22.00	
L.S.D 0.05		Zeolite mineral	2.235		
		Seaweed extract (SWE)	2.235		
		Interference	4.027		

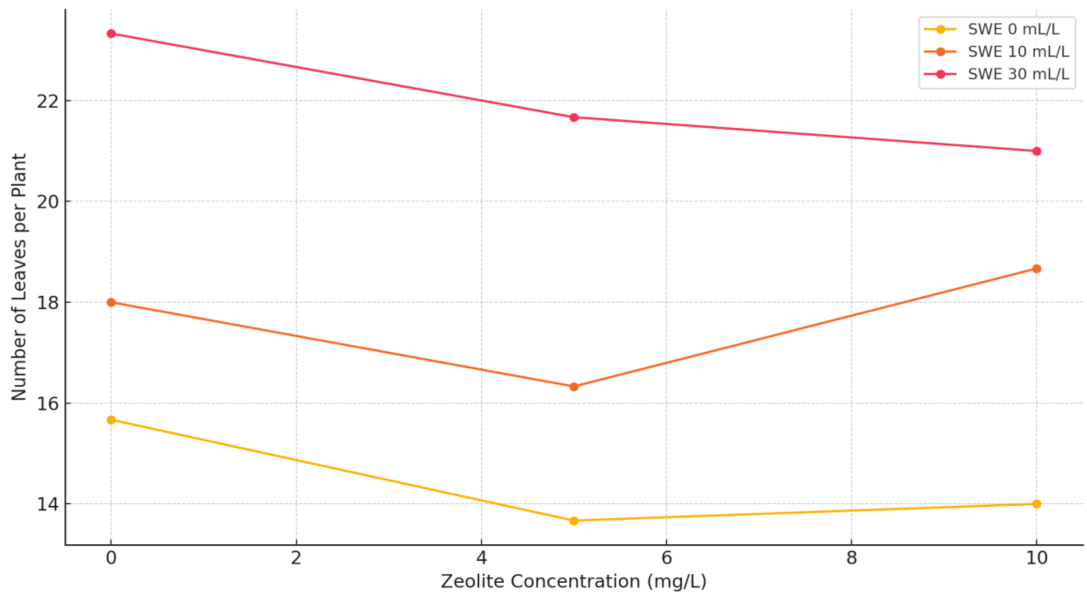

Figure 3. Effect of Different Concentrations of Seaweed Extract (SWE) and Zeolite on the Number of Leaves per Plant in *Rosa damascena.*

3.3. Number of Branches (Branches Plant−1)

The results presented in **Table 5** and illustrated in **Figure 4** confirm that SWE had a statistically significant positive effect on the number of lateral branches in the Rosa damascena plants. In particular, the average number of branches increased from 4.89 to 6.33 branches per plant as the SWE concentration highlighted the stimulating effects, depending on the dose of the SWE, from 0 to 30 mL L^{-1}. In contrast, the zeolite mineral did not show a significant effect, as the differences between its concentrations of 0, 5, and 10 mg L^{-1} were not statistically meaningful (LSD = 0.863). In particular, the highest number of branches (6.67) was seen in a combination of 0 mg L^{-1} zeolite with 30 mL L^{-1} SWE, while the lowest number, 4.33, was recorded in 5 mg L^{-1} zeolite treatment without SWE. These conclusions are supported by Jaafer et al. [32]. However, the treatment without zeolite and high SWE clearly improved others, which suggests that the zeolite may not be called effective for this specific feature. **Figure 4** demonstrates a consistent upward trend in branching as SWE concentration increases, regardless of zeolite level. However, treatments with no zeolite and high SWE outperformed others, suggesting that zeolite may not synergize as effectively for this specific.

Table 5. Effect of Zeolite Addition, Seaweed Extract Foliar Spray, and Their Interaction on the Number of Lateral Branches per Plant (Branches plant−1) in *Rosa damascena.*

Treatments		**Seaweed Extract (SWE) mL L^{-1}**			**The Average Effect of the Zeolite Mineral**
		0	10	30	
Zeolite mineral mg L^{-1}	0	5.00	6.00	6.67	5.89
	5	4.33	6.00	6.00	5.44
	10	5.33	6.00	6.33	5.89
Average effect of Seaweed extract (SWE)		4.89	6.00	6.33	
L.S.D 0.05		Zeolite mineral	0.863		
		Seaweed extract (SWE)	0.863		
		Interference	1.494		

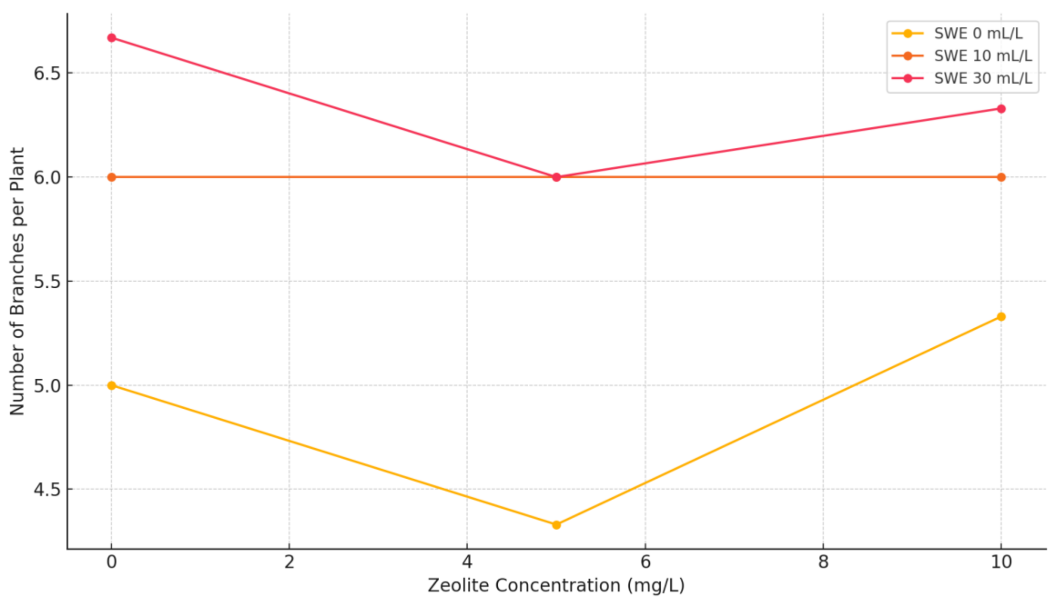

Figure 4. Effect of Seaweed Extract (SWE) and Zeolite on the Number of Lateral Branches per Plant *Rosa damascena.*

3.4. Leaf Area Index (cm² Plant−1)

The figures presented in **Table 6** and **Figure 5** show that SWE has increased the leaf area ofRosa damascena plants sharply. Since the SWE concentration increased from 0 to 30 mL of L⁻, the average leaf range increased from 22.47 cm to to 27.83 cm, indicating a strong role of marine algae bioactive compounds in promoting leaf expansion. While Zeolite alone did not affect the leaf area (LSD = 2944) significantly, the interaction with SWE revealed a very important impact. The combination of 30 mL L^{-1} and 5 mg L^{-1} zeolite with SWE gave the highest recorded value of 30.51 cm of intestines, suggesting a synergistic effect that is more than the contribution of both inputs when used separately. The increase in the leaf area can be attributed to Rosa damascena's hormonal and nutritional materials, which are known for stimulating cell divisions, photosynthetic activity and nutrients [33,34]. Moreover, zeolite enhances soil structure and water retention, which may complement the foliar activity of SWE by improving root uptake and internal nutrient flow. **Figure 5** The influence is well portrayed by for which the significant peak at zeolite of 5 mg L^{-1} with 30 mL L^{-1} of SWE. The enhancement observed was not achieved with any either lower or higher dose of zeolite when combined with SWE, suggesting that there could be an optimum effect of the SWE at moderate doses of zeolite.

Table 6. Effect of Zeolite Application, Seaweed Extract Foliar Spray, and Their Interaction on Leaf Area (cm² plant−1) of *Rosa damascena.*

Treatments		**Seaweed Extract (SWE) mL L^{-1}**			**The Average Effect of the Zeolite Mineral**
		0	10	30	
Zeolite mineral mg L^{-1}	0	22.88	25.90	24.70	24.49
	5	22.72	24.18	30.51	25.80
	10	21.81	26.67	28.27	25.58
Average effect of Seaweed extract (SWE)		22.47	25.58	27.83	
L.S.D 0.05		Zeolite mineral	2.944		
		Seaweed extract (SWE)	2.944		
		Interference	5.099		

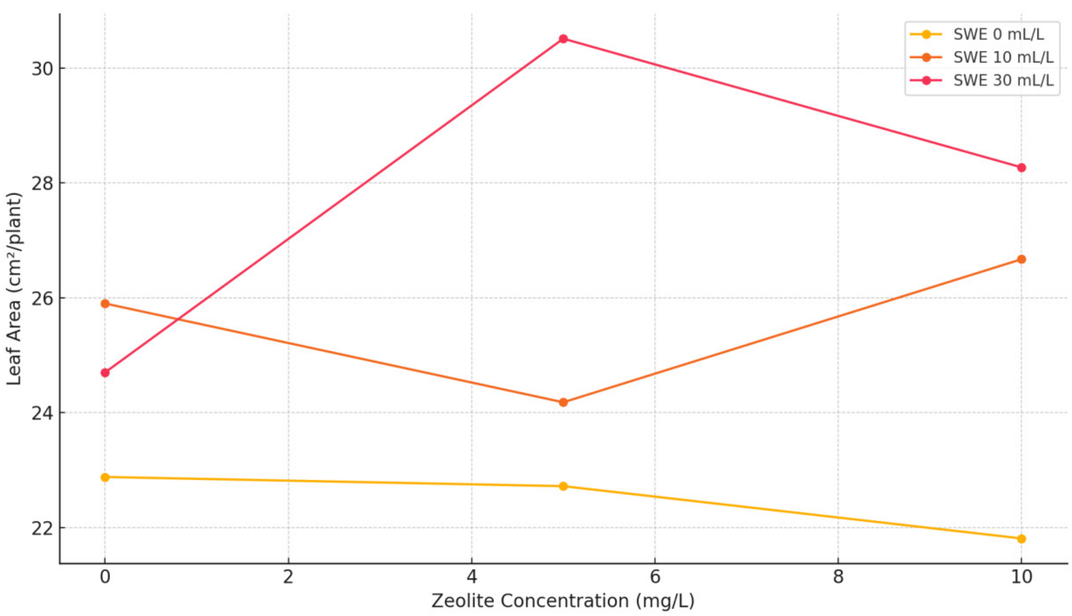

Figure 5. Effect of Seaweed Extract (SWE) and Zeolite on Leaf Area in *Rosa damascena.*

3.5. Root Dry Weight (g)

The results presented in **Table 7** and **Figure 6** suggest that SWE had statistically significant and positive effects on the root weight of the Rosa damascena plants. As the SWE concentration increased from 0 to 30 mL of L⁻, the average root length increased from 5.71 g to 16.45 g. In addition, the zeolite showed a significant impact, especially at 5 mg L^{-1} concentration, which improved other levels. The most obvious result was seen in the treatment of a combination of 30 mL L^{-1} and 5 mL L^{-1} with SWE and zeolite, which resulted in the highest root weight, 18.63 g. In contrast, the lowest dry weight, 4.73 g, was in the treatment without 5 mg L^{-1} zeolite, suggesting that zeoliteis insufficient to encourage root development alone, and SWE plays an important role.

Table 7. Effect of Zeolite Addition and Seaweed Extract Foliar Spray and Their Interaction on Root Dry Weight (g) of *Rosa damascena.*

Treatments		**Seaweed Extract (SWE) mL L^{-1}**			**The Average Effect of the Zeolite Mineral**
		0	10	30	
Zeolite mineral mg L^{-1}	0	6.47	7.18	16.19	9.94
	5	4.73	11.00	18.63	11.46
	10	5.94	8.20	14.52	9.55
Average effect of Seaweed extract (SWE)		5.71	8.79	16.45	
L.S.D 0.05		Zeolite mineral	1.074		
		Seaweed extract (SWE)	1.074		
		Interference	1.861		

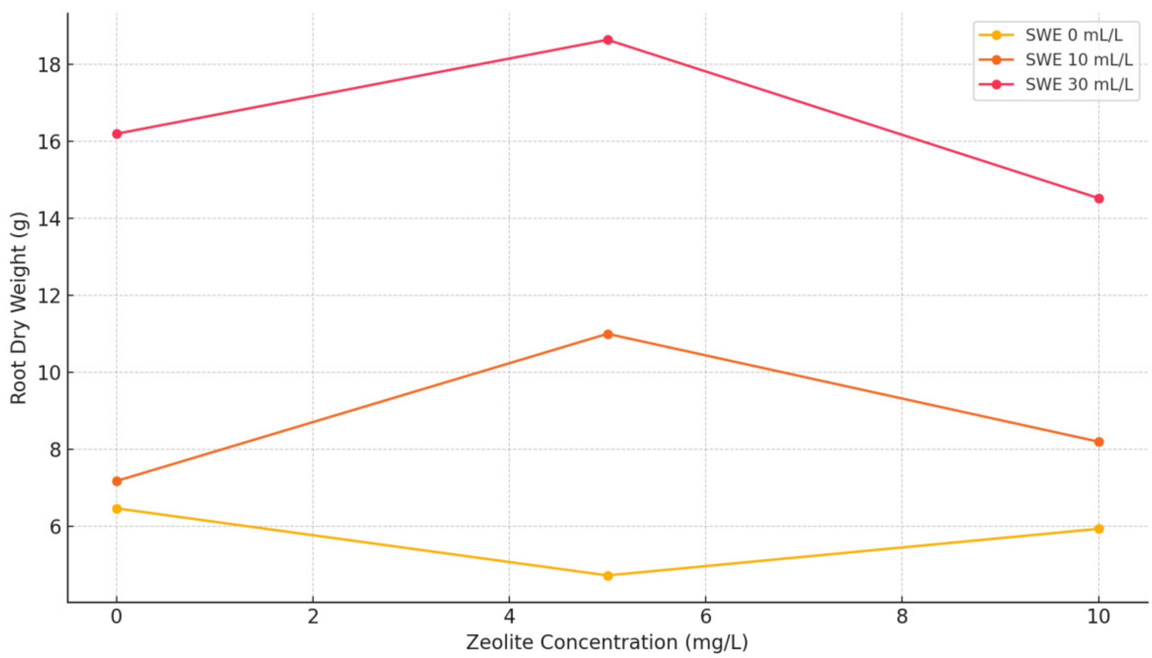

Figure 6. Effect of Seaweed Extract (SWE) and Zeolite on Root Dry Weight in *Rosa damascena.*

The results indicated the substantially synergistic effect of SWE with zeolite. Zeolite also improves the physical quality of the soil as well as increasing its cation exchange capacity, which in turn will provide better water and nutrient holding capacity around plant roots. This interpretation is consistent with the findings of work by Shahad et al. [35] who reported improvement of root biomass and architecture in roses due to application marine algae extracts from padina Antarctica. The bio-stimulant effect of seaweed extracts can be attributed to the presence of betaine, cytokinins and oligosaccharides which promote shoot and root growth [36]. Additionally, Khan et al. [37] stated that seaweeds extract promote root systems development through hormonal stimulation Improving nutrient uptake efficiency. As clearly illustrated by **Figure 6**, the root biomass obviously increased at 30 mL L^{-1} SWE and a sharp peak was observed while treated with zeolite (5 mg L^{-1}) combined with SWE. It implies that the combined application of moderate mineral amendment (zeolite) and an optimal biostimulant dose (SWE) may be favorable for the improvement of root functions in Rosa damascena.

3.6. Dry Weight (g)

The results shown in **Table 8** and illustrated in **Figure 7** provide that the SWE increased the dry weight of Rosa damascena plants. The average dry weight increased from 10.24 g to 19.18 g as the concentration of SWE increased from 0 to 30 mL of L^{-1}, highlighting the strong bio-stimulating effect of marine algae-ritual compounds on the development of vegetation shoots [38]. On the other hand, zeolite had no statistically significant effect since the differences between concentrations of zeolite were lower than the least significant difference (2786). But the interaction effect of zeolite × SWE was extremely significant, especially that of 10 mg L^{-1} zeolite and 30 mL L^{-1} SWE. However, the lowest dry weight (9.43 g) of shooting was observed in treatment10 mg L^{-1} zeolite without SWE. Moreover, SWE contains bioactive compounds including cytokinins, auxins, amino acids and vitamins that are also associated with inducement of cell division and acceleration of chlorophyll synthesis thereby promoting photosynthesis that leads to the development of shoot biomass. These results are in line with earlier reports of Hamid and Shahad [39], reported the mechanism of the marine algae extracts which increases the photosynthetic efficiency, nutritional revitalization and general plant health under normal as well as stress condition. **Figure 7** demonstrates these trends; the shoot dry weight increases substantially with SWE addition, particularly when combined with 10 mg/L zeolite. The sharp increase in growth parameters at higher SWE and zeolite levels suggests that optimal bio-stimulant and mineral balance contributes to biomass outcomes, which is also in line with long-term yield forecasting approaches like those proposed in the research of Abbas et al. and Farajzadeh et al. [40,41].

Table 8. Effect of Zeolite Application and Seaweed Extract Spraying and Their Interaction on Shoot Dry Weight (g) of *Rosa damascena.*

Treatments		**Seaweed Extract (SWE) mL L^{-1}**			**The Average Effect of the Zeolite Mineral**
		0	10	30	
Zeolite mineral mg L^{-1}	0	10.81	20.01	18.59	16.47
	5	10.47	19.21	17.93	15.87
	10	9.43	17.74	21.03	16.07
Average effect of Seaweed extract (SWE)		10.24	18.99	19.18	
L.S.D 0.05		Zeolite mineral	2.786		
		Seaweed extract (SWE)	2.786		
		Interference	4.826		

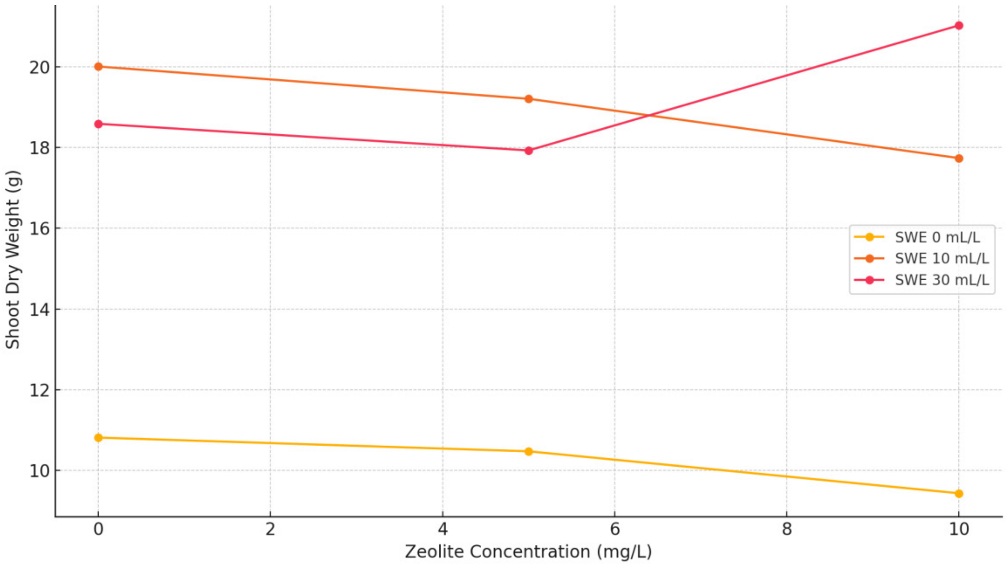

Figure 7. Effect of Seaweed Extract (SWE) and Zeolite on Shoot Dry Weight in *Rosa damascena.*

4. Conclusions

The findings from this study show the beneficial effects of marine algae extracts (SWE) on the vegetation development of the Rosa damascena plant. Significant improvements were observed in all measured treatments, including the height of the plant, the number of leaves and branches, the leaf area, the root weight, and the root dry weight and shoot dry weight, especially at the highest concentration of 30 mg L^{-1}. As a result of the interaction between these two changes, the highest values recorded in many parameters as a result of the highest values indicate that the zeolite can increase the bioavailability and effect of the nutrients distributed through maritime algae extracts. Overall, the results emphasize the ability to integrate natural biostimulants, such as marine algae extracts, with mineral soil, such as zeolites. This combination not only promotes the growth of healthy plants but also represents a permanent and environmentally conscious approach to improve the productivity of plants such as Rosa damascena.

Author Contributions

All authors contributed equally to the writing and preparation of the manuscript. Each author was involved in the preparation of the original draft, as well as the revision and final approval of the submitted version. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Not applicable.

Data Availability Statement

The data that supports the findings of this study will be available on request from the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest.

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