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The effect of irrigation water salinity, soil salinity, and their interaction on the growth, yield, and some qualitative characteristics of the salicornia plant (*Salicornia europaea* L.)

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ABSTRACT
A pot experiment was conducted in Kirkuk Governorate/Hawija District/Al-Riyadh Sub-district during the 2025 growing season to study the effect of soil salinity levels (3.64, 7.04, 10.32, and 14.00 dS m^{-1}) and Irrigation Water Salinity (4.00, 8.00, 12.00, and 16.00 dS m^{-1}) on the vegetative growth, yield, and qualitative characteristics of Salicornia cultivar ICBA-10. The experiment was conducted using a complete block design (RCBD) with six replications. Fresh and dry weight measurements were taken from three replications, while yield measurements were taken from the remaining three. The results showed that both soil and Irrigation Water Salinity had a significant effect on the studied characteristics. The average plant height increased from 44.44 cm at the lowest soil salinity level to 55.50 cm at the highest level. It also increased with increasing Irrigation Water Salinity, from 45.23 cm to 54.58 cm. The highest plant height (60.40 cm) was recorded at the intersection of the highest soil and Irrigation Water Salinity levels. Regarding the fresh weight of the foliage, it increased from 177.57 g plant^{-1} at the lowest soil salinity level to 225.29 g plant^{-1} at the highest level. With increasing Irrigation Water Salinity, it increased from 183.07 g plant^{-1} to 223.34 g plant^{-1}, while the highest fresh weight (252.07 g plant^{-1}) was recorded at the intersection of the two highest salinity levels. Dry weight increased from 36.36 to 46.95 g plant^{-1} with soil salinity and from 37.74 to 45.83 g plant^{-1} with Irrigation Water Salinity, with the highest dry weight (52.21 g plant^{-1}) recorded at the overlap between the two highest levels. Grain yield gradually increased from 5.53 g plant^{-1} to 8.90 g plant^{-1} with soil salinity and from 5.66 to 9.06 g plant^{-1} with Irrigation Water Salinity, with the highest yield (11.33 g plant^{-1}) recorded at the overlap between the two highest levels. Likewise, protein concentration improved from 20 % to 22.50 %. The highest concentrations of protein and oil (23.84% and 28.40% respectively) were recorded at the intersection of the highest soil and irrigation water salinity levels. were reached at the overlap between the two highest levels of soil salinity and irrigation water, indicating a synergistic effect that promotes vegetative growth, dry matter accumulation, and plant quality yield.
KEYWORDS: *Salicornia europaea* L., Irrigation Water Salinity, Soil Salinity, Plant Growth, Grain Yield, Quality Characteristics.

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تأثير ملوحة مياه الري وملوحة التربة والتداخل بينهما في النمو والحاصل وبعض الصفات النوعية لنبات الساليكورنيا(*Salicornia europaea L.*)

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الملخص
أُجريت تجربة أصص في محافظة كركوك/قضاء الحويجة/ناحية الرياض خلال الموسم الزراعي 2025، لدراسة تأثير مستويات ملوحة التربة (3.64، 7.04، 10.32، و14.00 ديسي سيمنز م$^{-1}$) وملوحة مياه الري (4.00، 8.00، 12.00، و16.00 ديسي سيمنز م$^{-1}$) في النمو الخضري والحاصل والصفات النوعية لصنف الساليكورنيا **ICBA-10.** نُفذت التجربة باستخدام تصميم القطاعات العشوائية الكاملة **(RCBD)** وبست مكررات، حيث أُخذت قياسات الوزن الطري والجاف من ثلاث مكررات، بينما أُخذت قياسات الحاصل من الثلاث مكررات الأخرى. أظهرت النتائج أن كلاً من ملوحة التربة وملوحة مياه الري كان لهما تأثير معنوي في الصفات المدروسة. إذ ازداد متوسط ارتفاع النبات من 44.44 سم عند أقل مستوى لملوحة التربة إلى 55.50 سم عند أعلى مستوى، كما ازداد مع زيادة ملوحة مياه الري من 45.23 سم إلى 54.58 سم. وسُجل أعلى ارتفاع للنبات (60.40 سم) عند التداخل بين أعلى مستويين من ملوحة التربة ومياه الري. أما بالنسبة للوزن الطري للمجموع الخضري، فقد ازداد من 177.57 غم نبات$^{-1}$ عند أقل مستوى لملوحة التربة إلى 225.29 غم نبات$^{-1}$ عند أعلى مستوى، كما ازداد مع زيادة ملوحة مياه الري من 183.07 إلى 223.34 غم نبات$^{-1}$، في حين سُجل أعلى وزن طري (252.07 غم نبات$^{-1}$) عند التداخل بين أعلى المستويات. وبالنسبة للوزن الجاف، فقد ارتفع من 36.36 إلى 46.95 غم نبات$^{-1}$ مع زيادة ملوحة التربة، ومن 37.74 إلى 45.83 غم نبات$^{-1}$ مع زيادة ملوحة مياه الري، وسُجل أعلى وزن جاف (52.21 غم نبات$^{-1}$) عند التداخل بين أعلى المستويات.

كما ازداد حاصل الحبوب تدريجياً من 5.53 إلى 8.90 غم نبات$^{-1}$ مع زيادة ملوحة التربة، ومن 5.66 إلى 9.06 غم نبات$^{-1}$ مع زيادة ملوحة مياه الري، في حين سُجل أعلى حاصل (11.33 غم نبات$^{-1}$) عند التداخل بين أعلى المستويات. كذلك تحسن محتوى البروتين من 20% إلى 22.50%. وسُجلت أعلى تراكيز البروتين والزيت (23.84% و28.40% على التوالي) عند التداخل بين أعلى مستويات ملوحة التربة ومياه الري. تشير هذه النتائج إلى وجود تأثير تآزري بين ملوحة التربة وملوحة مياه الري يعزز النمو الخضري وتراكم المادة الجافة وجودة الحاصل في نبات الساليكورنيا.
الكلمات المفتاحية :الساليكورنيا(***Salicornia europaea L.***) ، ملوحة مياه الري، ملوحة التربة، نمو النبات، حاصل الحبوب، الصفات النوعية.

INTRODUCTION

Salicornia (*Salicornia europaea* L.) is among promising halophytes that have attracted widespread attention in recent decades because of its special ability to survive and grow under saline conditions and tolerance to elevated levels of salts in soil and irrigation water [1]. Salicornia, which belongs to the Amaranthaceae family is found naturally in coastal locations and marshes as well as semi-arid areas [2]. Soil studies have shown that it can be used as a forage, oilseed, and food crop; moreover, it has been successfully used for reclaiming saline lands and improving the physical and chemical properties of cultures. Salicornia seeds are also economically and nutritionally valuable products due to their relatively high oil content (25–33%) beyond proteins, carbohydrates, and mineral salts[3], particularly in saline soils with limited supplies of freshwater. Salinity is the most challenging problem to agriculture in arid and semi-arid areas. Higher concentration of dissolved salts in the soil solution result in negative osmotic potential, which restricts plant water uptake and influences multiple physiological processes like photo synthesis, cell division and elongation [4]. In addition, high salinity of irrigation water causes accumulation of salts in the root zone thus increasing ECe. This affects the absorption of macro- and micronutrients in a negative way leading to nutritional imbalances in the plant. reduced dry matter content [4, 5] as well as leaf length and number of branches [5]. While salinity is detrimental to the majority of traditional crops, Salicornia has specialized physiological and tolerance mechanisms that allow it to thrive in high-salinity environments. It is more salt-tolerant than many other plants, because of mechanisms like accumulation of ions in vacuoles, regulation of osmotic potential [4] and secretion or compartmentalization of salts in special storage tissues [5]. As a result, it is recognized as a strategic solution for the use of saline and brackish water in agriculture and alleviate pressure on freshwater resources particularly in arid and semi-arid areas facing soil and water degradation due to salinization. However, the degree of salinity response varies depending on the soil salinity level and irrigation water quality. This necessitates studying the interaction between these two factors on the plant's vegetative and productive characteristics in order to determine optimal tolerance limits and improve production under saline stress conditions [7,8].

Given the scarcity of local studies addressing the interaction between soil and Irrigation Water Salinity on the growth, productivity, and quality of Salicornia, the need has arisen to investigate this plant's response to different salinity levels in the local environment. Therefore, this study aimed to evaluate the effect of varying levels of soil salinity, Irrigation Water Salinity, and the interaction between them on the vegetative, productive, and qualitative characteristics of Salicornia grains, by analyzing the plant's response in terms of its height, fresh and dry weight of the vegetative mass, grain yield, and its chemical components.

MATERIALS AND METHODS

1- Experiment and Analysis of the Study Soils

A plastic pot experiment was conducted in Kirkuk Governorate – Hawija District / Al-Riyadh (in the wooden shade structure of Al-Riyadh Mixed Vocational Preparatory School) during the 2025 growing season, The seeds were sown on March 15, 2025, and harvested on July 10, 2025. Plastic pots with a capacity of 16 kg of soil were used. Soils with varying salinity were collected from several locations in Al-Riyadh Sub-district / Kirkuk Governorate. They were then air-dried, finned, and passed through a 2 mm sieve for homogenization before being packed (16 kg pot soil^{-1}). Representative samples were taken from each soil, air-dried, and passed through a 2 mm sieve to determine some chemical and physical properties before planting (Table 1.)

Salicornia seeds (Category ICBA-10) were sown on March 15, 2025, at a rate of 6 seeds per pot. After germination, thinning was carried out to reduce the number of plants to 3 per pot.

Fully decomposed organic fertilizer (cow manure) was added at a rate of 2% of the soil weight , equivalent to 320 g per pot^{-1}, and mixed thoroughly into the soil two weeks before planting. Chemical fertilizers were added according to the approved recommendations for salt-tolerant crops. Specifically (2% organic matter was added to all treatments with the aim of standardizing the basic properties of the soil between the different treatments, and improving the physical and chemical properties of the soil, such as its aeration, water retention, and nutrient availability, so that the effect of soil salinity and irrigation water salinity can be accurately assessed without the effect of variations in soil quality), 150 kg N ha^{-1} (2.40 g N pot^{-1}) was added as urea (46% N), 80 kg P_2O_5 ha^{-1} (1.28 g pot^{-1}) as triple superphosphate (TSP), and 60 kg K_2O ha^{-1} (0.96 g pot^{-1}) as potassium sulfate (41.5% K). Phosphorus and potassium were applied in a single application before planting, while nitrogen fertilizer was applied in two installments: the first two weeks after germination and the second 45 days after planting [9].

Irrigation was carried out when the soil moisture reached about 80% of the field capacity [10]. while maintaining the specified salinity levels throughout the growth period to avoid salt accumulation at the bottom of the pot. Electrical conductivity (EC) was measured before each irrigation using an EC meter to ensure the stability of the salinity level.

Table 1. Some Physical and Chemical Properties of the Studied Soils

Property	Unit	S_1	S_2	S_3	S_4	Method Used
Sand	g kg^{-1}	500	508	515	520	
Clay	g kg^{-1}	292	284	276	270	Pipette method [11].
Silt	g kg^{-1}	208	208	209	210	
Texture	—	Clay loam	Clay loam	Loam	Loam	Texture triangle
Organic matter (O.M.)	g kg^{-1}	7.8	6.3	4.9	3.8	Pipette method [11].
Calcium carbonate ($CaCO_3$)	g kg^{-1}	20.9	24.7	28.2	31.5	Gravimetric method [12].
Cation exchange capacity (CEC)	cmol kg^{-1}	20.62	16.81	12.73	9.44	Pipette method [11].
pH (1:1)	—	7.53	7.69	7.84	7.98	pH meter [12].
EC (1:1)	dS m^{-1}	3.64	7.04	10.32	14.00	EC meter [12].
Available nitrogen	mg kg^{-1}	24.6	19.7	14.9	10.8	Micro-Kjeldahl method (11)
Available phosphorus	mg kg^{-1}	9.1	7.4	5.6	3.5	Pipette method [11].
Available potassium	mg kg^{-1}	141	126	110	93	Pipette method [11].

2-Experimental treatments and design:

The experiment was conducted as a factorial experiment (4 x 4) using a randomized complete block design (RCBD) with six replicates per treatment. It included two factors:

2-1 The first factor (soil salinity):

The study included four soil salinity levels of (3.64, 7.04, 10.32, and 14.00 dS m^{-1}), (To represent a salinity gradient starting from mild to high salinity) designated as (S_1, S_2, S_3, and S_4), respectively.

2-2 The second factor (Irrigation Water Salinity):

Irrigation water was prepared by dissolving calculated amounts of sodium chloride (NaCl) in ordinary water to obtain electrical conductivity levels of (4.00, 8.00, 12.00, 16.00) dS m^{-1} (as shown in Table 2), and they were designated by the symbols (W_1, W_2, W_3, W_4) respectively.

Table 2. Amounts of sodium chloride (NaCl) added to prepare different levels of Irrigation Water Salinity

Treatment	Target EC (dS m^{-1})	Base EC (dS m^{-1})	Added EC (dS m^{-1})	NaCl (g L^{-1}) = Added EC x 0.64	NaCl per 100 L (g)

W1	4.00	1.10	2.90	2.90 x 0.64 = 1.86	186
W2	8.00	1.10	6.90	6.90 x 0.64 = 4.42	442
W3	12.00	1.10	10.90	10.90 x 0.64 = 6.98	698
W4	16.00	1.10	14.90	14.90 x 0.64 = 9.54	954

The calculations were performed to obtain the required salinity level based on [14].

3- Studied Traits:

Six replicates were used for each treatment. Three replicates were harvested at 60 days of age (May 14, 2025) to measure certain vegetative growth traits, while the other three replicates were left to reach full maturity (July 10, 2025) to measure yield traits. The studied traits are detailed below:

a) **Fresh plant weight (g plant^{-1}) :** The fresh weight of each plant was determined using a sensitive electronic balance. The average fresh weight per experimental unit was then calculated, and the results were recorded on (g plant^{-1}).
b) **Dry plant weight (g plant^{-1}) :** Samples were dried in an air oven at 70°C for 72 hours until the weight stabilized.
c) **Plant height (cm):** Height was measured from the soil surface to the top of the growing tip, with an average of three plants per pot. The final average was then calculated from the average of three pots. 2-3-4 Seed Yield (g plant^{-1}): The weight of the seed yield of three plants was divided by the number of plants to obtain the seed yield per plant.
d) **Seed Protein Content (%):** The nitrogen content of the seeds was calculated using the Kjeldahl apparatus. [15] The following equation was then applied: Protein content = Nitrogen content x 6.25
e) **Seed Oil Content (%):** Random samples of grains were taken, and the percentage of oil was estimated using the Soxhelet apparatus as described in reference [16].

4- Statistical Analysis : The data were statistically analyzed using analysis of variance (ANOVA) within a factorial design within a randomized complete block design (RCBD) using SAS software. The arithmetic means were compared at a significance level of 0.05 using the least significant difference (LSD) test [17].

RESULTS AND DISCUSSION

Plant Height (cm)

The results in Table (3) show that Irrigation Water Salinity had a significant effect on the height of Salicornia plants. Plant height increased gradually with increasing salinity levels from 4.00 to 16.00 dS m^{-1}. The highest average height was recorded at 16.00 dS m^{-1}, reaching 54.58 cm, followed by 12.00 dS m^{-1} with an average of 51.48 cm, then 8.00 dS m^{-1} (48.91 cm). The lowest average height was recorded at 4.00 dS m^{-1}, at 45.23 cm.

The effect of soil salinity was also significant, with the highest average height recorded at 14.00 dS m^{-1}. The highest elevation was 55.50 cm, followed by a level of 10.32 dS m^{-1} with an average elevation of 51.23 cm, then a level of 7.04 dS m^{-1} (49.03 cm), while the elevation decreased to 44.44 cm at a level of 3.64 dS m^{-1}.

The interaction between Irrigation Water Salinity and soil salinity had a significant effect. The interaction of 14.00 dS m^{-1} soil x 16.00 dS m^{-1} irrigation water resulted in the highest elevation of 60.40 cm, while the lowest elevation at the interaction of 3.64 dS m^{-1} soil x 4.00 dS m^{-1} irrigation water resulted in an average elevation of 41.30 cm.

Table 3. Effect of soil salinity, Irrigation Water Salinity and the interaction between them on the height of Salicornia plants (cm)

Soil Salinity (dS m^{-1})	Irrigation Water Salinity (dS m^{-1})				Mean Soil Salinity (dS m^{-1})
	4.00	8.00	12.00	16.00	
3.64	41.30	43.54	44.70	48.20	44.44
7.04	43.70	47.40	51.20	53.80	49.03
10.32	46.60	50.10	52.30	55.90	51.23
14.00	49.30	54.60	57.70	60.40	55.50
Mean Irrigation Water Salinity (dS m^{-1})	**45.23**	**48.91**	**51.48**	**54.58**	**50.05**
$L.S.D_{0.05}$	**Water**		**Soil**		**Water x Soil**
	3.423		3.854		6.751

Fresh Weight of the Shoot System (g $plant^{-1}$)

The results in Table (4) indicate a significant effect of Irrigation Water Salinity. A level of 16.00 dS m^{-1} recorded the highest average fresh weight at 223.34 g $plant^{-1}$, followed by 12.00 dS m^{-1} (207.41 g $plant^{-1}$), then 8.00 dS m^{-1} (195.29 g $plant^{-1}$), and the lowest average at 4.00 dS m^{-1} (183.07 g $plant^{-1}$). Soil salinity also had a significant effect, with a level of 14.00 dS m^{-1} recording the highest average fresh weight at 225.29 g $plant^{-1}$, followed by 10.32 The average fresh weight was 208.95 g $plant^{-1}$, followed by 7.04 dS m^{-1} (average 197.29 g $plant^{-1}$), with the lowest average weight at 3.64 dS m^{-1} (177.57 g $plant^{-1}$).

The interaction between the two study factors showed significant differences. The treatment of 14.00 dS m^{-1} (soil) x 16.00 dS m^{-1} (irrigation water) resulted in the highest fresh weight of 252.07 g $plant^{-1}$, while the lowest weight was 3.64 dS m^{-1} (soil) x 4.00 dS m^{-1} (irrigation water) (163.43 g $plant^{-1}$).

Table 4. Effect of Soil Salinity, Irrigation Water Salinity, and Their Interaction on the Fresh Weight of the Shoot System (g plant^{-1})

Soil Salinity (dS m^{-1})	Irrigation Water Salinity (dS m^{-1})				Mean Soil Salinity (dS m^{-1})
	4.00	8.00	12.00	16.00	
3.64	163.43	172.55	180.77	193.54	177.57
7.04	177.31	189.00	204.00	218.84	197.29
10.32	188.76	207.00	211.14	228.90	208.95
14.00	202.78	212.61	233.71	252.07	225.29
Mean Irrigation Water Salinity (dS m^{-1})	**183.07**	**195.29**	**207.41**	**223.34**	**202.28**
L.S.D $_{0.05}$	**Water**		**Soil**		**Water x Soil**
	13.021		14.089		25.547

Dry Weight of the Shoot System (g plant^{-1})

The results in Table (5) indicate a significant effect of soil salinity levels. A soil level of 14.00 dS m^{-1} recorded the highest average dry weight of 46.95 g plant^{-1}, followed by 10.32 with an average of 42.75 g plant^{-1}, then 7.04 with an average of 39.78 g, and the lowest average at 3.64 with 36.36 g plant^{-1}. Irrigation Water Salinity also showed significant differences, with a level of 16.00 dS m^{-1} recording the highest average of 45.83 g plant^{-1}, and a level of 4.00 dS m^{-1} recording the lowest average of 37.74 g Plant^{-1}).

Significant variations were found in the two-way interaction between the two study components, with the greatest dry weight of 14.00 dS m^{-1} x Irrigation Water Salinity 16.00 dS m^{-1} recorded the highest dry weight of 52.21 g plant^{-1}, while the lowest weight was at 3.64 x 4.00 (33.74 g plant^{-1}).

Table 5. Effect of Salinity of Soil and Irrigation Water, and Their Interaction on the Dry Weight of the Shoot System (g plant^{-1})

Soil Salinity (dS m^{-1})	Irrigation Water Salinity (dS m^{-1})				Mean Soil Salinity (dS m^{-1})
	4.00	8.00	12.00	16.00	
3.64	33.74	35.01	36.42	40.27	36.36
7.04	36.01	37.89	41.22	44.01	39.78
10.32	39.11	40.92	44.16	46.81	42.75
14.00	42.10	44.66	48.81	52.21	46.95
Mean Irrigation Water Salinity (dS m^{-1})	**37.74**	**39.62**	**42.65**	**45.83**	**41.46**

L.S.D $_{0.05}$	**Water**	**Soil**	**Water x Soil**
	2.534	2.881	5.011

The results in Tables 3, 4, and 5 indicate that Irrigation Water Salinity and Plant height was clearly and significantly impacted by soil salinity and the fresh and dry weight of the vegetative parts. The data showed a gradual increase in plant height as salinity levels increased from 4.00 to 16.00 dS m^{-1} in the irrigation water. This is attributed to the plant's obligate salinity, as moderate to high salinity levels promote intracellular osmotic balance and stimulate the regulation of essential ion uptake, such as sodium and potassium, thus contributing to improved stem elongation and overall vegetative growth [6,18]. the fresh weight of the vegetative parts, a significant increase was observed with increasing salinity. This increase is explained by the fact that moderate to high salinity enhances the plant's osmotic adaptation through the accumulation of non-toxic ions and organic compounds that regulate osmotic pressure, in addition to activating antioxidant enzyme systems. This increases productive photosynthetic efficiency and fresh mass [19]. Advancing moisture accumulation and combining the physiological mechanism established through soil-saline interaction to Irrigation Water Salinity.

The vegetative system dry weight of the plants also showed similar trends to plant height and fresh weight results. In contrast, the average dry weight was higher at high salinity level (soil salinity 14.00 dS m^{-1} and Irrigation Water Salinity 16.00 dS m^{-1}) while it was lowest at low level of salinity. The salt-resistant nature of the plant is credited for this. Salts solubilized in the environment of the roots create osmotic equilibrium conditions, filling cells with fluid and activate physiological processes between carbohydrates and organic material accumulation. This leads to a higher accumulation of dry material in the plant tissues. The promotion of vegetative growth under these conditions would therefore be caused by accumulation of photosynthetic products that can be converted into stable vegetative mass and therefore this analysis also reflects the ability of plant to convert photosynthetic products in a stable vegetative mass. These findings corroborate with previous studies overall, indicating that some halophytic plants (like Salicornia) had increases in growth trends from moderate to high and hyper saline conditions. Salts enhance osmotic balance and promote succulence, leading to increased vegetative growth, as evidenced by higher plant dry weight [20,21].

Grain Yield (g plant^{-1})

Significant variations between the experimental treatments are displayed in Table (6) . The soil level of 14.00 dS m^{-1} recorded the highest yield of 8.90 g plant^{-1}, significantly higher than the salinity levels of (10.32, 7.04, and 3.64) dS m^{-1}, which recorded averages of (7.68, 6.58, and 5.53 g plant^{-1}) respectively. As for Irrigation Water Salinity, the level of 16.00 dS m^{-1} recorded the highest average yield of 9.06 g plant^{-1}, with significant increases of (60.08, 40.90, and 20.00%) compared to the salinity levels of (4.00, 8.00, and 12.00). 16.00 dS m^{-1}, respectively. The interaction of 14.00 dS m^{-1} (soil) x 16.00 dS m^{-1} (irrigation water) resulted in the highest yield of 11.33 g $plant^{-1}$, while the lowest yield was recorded at 3.64 dS m^{-1} (soil) x 4.00 dS m^{-1} (irrigation water), which yielded 4.71 g $plant^{-1}$.

As shown in Table (6), soil salinity, Irrigation Water Salinity and their interaction significantly affected Salicornia grain yield. Higher salinity levels significantly improve grain production in comparison with lower that is clear [17].[18] As a rationale for this phenomenon, Salicornia represents an obligate halophyte and therefore the uptake of salts in their root system to some extent enhances the vigor of most physiological processes related with growth and production. At moderate to high levels of salinity, osmotic balance in plant cells allows the plant to maintain its water content and move minerals and nutrients through the tissues. This is beneficial for the efficiency of photosynthesis and carbohydrate formation, which is the main source of grain formation [22].

Sodium and potassium accumulate in vacuoles despite salt-stress; this has also been attributed to the improved grain yield observed under saline conditions. This is a key physiological process that serves to alleviate intracellular osmotic stresses and maintain overall cellular turgor pressure. This caused more plants become succulent and cells had a higher efficiency to retain water, which promoted photosynthesis and the activities of specific enzymes related to synthesize and transport organic compounds into reproductive organs. Improved grain formation and increased (indirectly) plant yield [23].

Improved vegetative parameters of the plant under salinity stress conditions are also proved to correlate positively with improved yield components and grain yield. Similar trends were observed in growth traits plant height, fresh weight and dry weight of vegetative parts (Tables 3, 4 and 5) with respect to salinity levels. The links between vegetative growth and yield are physiologically anticipated as taller plants with greater vegetative stature have a greater effective leaf area that enables the plant to capture more light energy for photosynthesis (Patrignani & Prudent). The higher fresh and dry weight of the aboveground parts corresponds to enhanced dry matter accumulation inside the plant, which contributes more quantity of photosynthetic products available for translocation and storage in grains during grain filling. Moreover, this beneficial effect is reinforced by the interaction between soil and irrigation water saline concentrations. For this balanced salinity of the soil and irrigation water, there will be more relative equilibrium conditions in the surrounding environment around roots followed by reducing shock due to sudden salt stress and helping the plant do it selectively. This is due to the improved root absorption of nutrients and water as well as the stimulation of plant defense and metabolic mechanisms, which encourage dry matter accumulation and enhance grain formation efficiency.

Table 6. Effect of Soil Salinity, Irrigation Water Salinity, and Their Interaction on grain Yield (g plant^{-1})

Soil Salinity (dS m^{-1})	Irrigation Water Salinity (dS m^{-1})				Mean Soil Salinity (dS m^{-1})
	4.00	8.00	12.00	16.00	
3.64	4.71	5.09	5.59	6.72	5.53
7.04	5.23	6.01	6.92	8.17	6.58
10.32	6.06	6.75	7.91	10.01	7.68
14.00	6.62	7.86	9.77	11.33	8.90
Mean Irrigation Water Salinity (dS m^{-1})	**5.66**	**6.43**	**7.55**	**9.06**	**7.17**
L.S.D $_{0.05}$	**Water**		**Soil**		**Water x Soil**
	0.602		0.692		1.115

Grain Protein Concentration (%)

The outcomes in Table (6) show that increased soil salinity significantly and positively affected the protein concentration in grains. The highest protein concentration (22.50 %) was recorded at a soil level of 14.00 dS m^{-1}, while the lowest concentration (20.00 %) was recorded at 3.64 dS m^{-1}.Irrigation Water Salinity also had a significant effect. The highest average concentration (22.35 %) was recorded at a level of 16.00 dS m^{-1}, and the lowest average concentration (20.14 %) was recorded at a level of 4.00 dS m^{-1}. The interaction between the two study factors showed significant differences, as the treatment 14.00 dS m^{-1} x 16.00 dS m^{-1} recorded the highest protein percentage of 23.84 %, and the lowest percentage was 3.64 dS m^{-1} x 4.00 dS m^{-1}, which amounted to 19.39 %.

Table 7. Effect of Soil Salinity, Irrigation Water Salinity, and Their Interaction on Grain Protein Concentration (%)

Soil Salinity (dS m^{-1})	Irrigation Water Salinity (dS m^{-1})				Mean Soil Salinity (dS m^{-1})
	4.00	8.00	12.00	16.00	
3.64	19.39	19.37	20.14	21.11	20.00
7.04	19.88	20.27	21.14	22.05	20.84
10.32	20.28	20.41	21.19	22.4	21.07
14.00	21.01	21.63	23.52	23.84	22.50
Mean Irrigation Water Salinity (dS m^{-1})	20.14	20.42	21.5	22.35	22.35
L.S.D $_{0.05}$	**Water**		**Soil**		**Water x Soil**
	1.052		1.280		1.981

Oil Concentration in the Grains (%)

The results presented in Table (8) indicate that both soil salinity and Irrigation Water Salinity had a significant effect on grain oil concentration. Increasing soil salinity from 3.64 to 14.00 dS m^{-1} caused a gradual increase in the mean oil concentration from 26.61 % to 28.19 %, increasing Irrigation Water Salinity from 4.00 to 16.00 dS m^{-1} raised the mean concentration from 27.32% to 29.10 %.

The interaction analysis shows that the highest oil concentration (30.39%) was recorded under highly saline soil (14.00 dS m^{-1}) combined with high-salinity irrigation water (16.00 dS m^{-1}), while the lowest concentration (26.61%) was observed under the lowest soil salinity (3.64 dS m^{-1}) and low-salinity irrigation water (4.00 dS m^{-1}). This indicates that the interactions between soil salinity and Irrigation Water Salinity can enhance oil accumulation in the grains.

Table (8): Effect of Soil Salinity, Irrigation Water Salinity, and Their Interaction on Grain Oil Concentration (%)

Soil Salinity (dS m^{-1})	Irrigation Water Salinity (dS m^{-1})				Mean Soil Salinity (dS m^{-1})
	4.00	8.00	12.00	16.00	
3.64	26.61	27.02	27.58	28.15	26.61
7.04	26.89	27.00	27.74	28.58	26.89
10.32	27.60	27.77	28.65	29.29	27.60
14.00	28.19	28.40	29.81	30.39	28.19
Mean Irrigation Water Salinity (dS m^{-1})	**27.32**	**27.55**	**28.45**	**29.10**	**27.32**
L.S.D $_{0.05}$	**Water**		**Soil**		**Water x Soil**
	1.049		1.164		1.809

According to the results in Tables (7) and (8), soil salinity, Irrigation Water Salinity and also their interactive effect on protein and oil content of Salicornia grass were significant. Generally, higher salinity levels cause a relative increase of these traits which could be explained by the healing mechanism of saline plants that is associated with salt stress adaptations.

With respect to the protein content present in the grains, it was found that higher levels of salinity also led to an increase in this substance which can be explained as Salicornia regulates osmotic balance at intracellular level through accumulation of inorganic ions (i.e., sodium, potassium) inside vacuoles. This helps keep the water or intracellular fluid content of the cells and optimizes metabolic processes. As a result, photosynthesis is initiated and more organic compounds are generated like amino acids (the main building blocks of proteins). This leads to a higher protein content of the grains eventually [24]. This increment may also be related to favorable vegetative growth features of the plants under various levels of salinity. The data obtained for previously discussed features, e.g., plant height, fresh weight and vegetative parts dry weight (Tables 3, 4 and 5), indicated a clear increase in the salinity. This enhancement results in a larger effective leaf area and increased photosynthetic efficiency, thus boosting the carbon- and nitrogen-based compound production required for protein synthesis in the plant. Furthermore, exposure to salt stress can stimulate the formation of specialized proteins known as stress proteins. These proteins help protect cells and maintain the stability of enzymes and other vital systems within the plant, contributing to the increased protein content in the grains [25].

As for the oil concentration in the grains, this is due to the ability of halophytic plants to modify their metabolic pathways under stress conditions. Moderate salinity leads to improved osmotic regulation and the maintenance of water balance within cells. This contributes to improved photosynthetic efficiency and increased carbohydrate production, which serves as the raw material for fatty acid and fat synthesis within the seeds, leading to an increase in grain oil [26]. Furthermore, higher grain oil content is associated with increased plant biomass and improved vegetative growth characteristics, such as plant height and increased fresh and dry weight of the foliage. This is because increased leaf area and photosynthetic activity in the leaves result in the production of larger quantities of photosynthetic products, which are involved in the fat synthesis pathways within the grains. On the other hand, moderate salinity may act as a catalyst for fat accumulation in seeds, as these fats are energy-rich compounds that contribute to protecting cell membranes and improving their stability under salt stress conditions. They also play a role in storing the energy necessary for seed germination in saline environments [27].

CONCLUSIONS

- Salicornia has shown strong expansion into environmental substrates with elevated soil and Irrigation Water Salinity levels for habitats that cannot support most vegetable crops. Salinity increased plant growth and vegetative biomass accumulation.
- The study suggested that maintaining a balance between soil and Irrigation Water Salinity can enhance plant productivity and yield.
- The findings indicated that salinity improves growth and productivity at high levels, but also enhances the qualitative properties of grains which include its protein and oil content.
- It is suggested to increase Salicornia farming in saline soils, especially in countries with soil salinity and water scarcity like Iraq. Its resistance to extreme environmental conditions allows it to be cultivated and produce in saline lands, thus serving as promising food content.
- More studies should be conducted to assess the capability of Salicornia as a phytoremediator for heavy metal-contaminated Soil & Water because halophytes have shown to absorb and

acumulate certain elements in plant tissues.

- Assess the potential S (salinity) threshold levels of salinity in both soil and irrigation water that will enhance grain quality, including oil and protein because of its nutritional as well as commercial significance.
- Perform trials of various Salicornia types or species under different environmental and agronomic conditions to ascertain the varieties best adapted to salinity tolerable, capable of reaching high productivity in arid and semi-arid environments.

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