

Analysis of the combined effect of irrigation water salinity, humic acid and potassium fertilizer on soluble calcium dynamics, soil pH and wheat plant height (*Triticum aestivum* L.)

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I. Abstract :

A pot experiment was conducted in one of the fields belonging to the Department of Soil Science and Water Resources at University of Sumer /Dhi Qar Governorate, using a silty clay loam soil, to study the combined effect of irrigation water salinity, humic acid, and potassium fertilizer on soluble calcium dynamics, soil pH, and wheat plant height. The experiment was designed according to the RCBD design, with three replications. The experiment included three factors: the first factor was irrigation water salinity at three levels (1, 2, 3, and 6 dS.m⁻¹) obtained from a drain east of Al-Rifai city, symbolized by the symbols S1, S2, and S3. The second factor is potassium fertilizer at two levels (150 and 250) kg K. ha⁻¹, symbolized by K1 and K2 respectively. The third factor was humic acid, which was added in different ways: soil addition (HT), foliar addition (HF), combined addition (HFT), and no addition (H0). The quantity is divided into three stages of growth: branching, elongation, and flowering.

Wheat seeds were planted on November 15th, 2025. Soluble calcium ions, soil pH, and plant height were measured at the end of the experiment (harvest stage). The results showed the following:

Adding salinity to the irrigation water significantly affected soluble calcium levels, with the highest value recorded at level S1 (6.62 mmol kg⁻¹ soil) and the lowest value at level S3 (6.12 mmol kg⁻¹ soil). Salinity also affected soil pH, with the highest value recorded at level S3 (7.86) and the lowest at level S1. Furthermore, it affected average plant height, with level S1 recording the highest average plant height at 67.58 cm. Potassium addition did not significantly affect soluble calcium levels or soil pH, but it significantly affected average plant height at level K2. Humic acid addition showed that HFT treatment resulted in the highest soluble calcium levels, soil pH, and plant height.

As for the two-way interaction treatments (S*K, S*H, and K*H), they recorded a significant effect on all the measured traits, while the three-way interaction (S*K*H) also recorded a significant effect on the studied traits in both the values of soluble calcium, where the treatment S1K1HFT recorded the highest value, which reached 7.06 mmol kg⁻¹ soil, and in the average plant height as well, as the average height reached 70.67 cm, while the treatment S3K2H0 recorded the highest value in the soil pH, which reached 8.06.

Keywords : Irrigation water salinity, potassium fertilizer, humic acid, soluble calcium, soil pH, wheat plant height.

II. Introduction

Potassium (K) is one of the essential macronutrients for plant growth and development, and it is the seventh most abundant element in the Earth's crust. This element is released into the soil through weathering and the decomposition of its constituent minerals. However, the released amounts are often insufficient to meet plant needs, especially in intensive farming systems and crop rotation. Therefore, potassium fertilization is an important agricultural practice for maintaining potassium balance in the soil and ensuring the sustainability of the agricultural production. The slight potassium shortage can affect the plant growth and reduce it, as well as affects the productivity, even if no obvious symptoms appear on the plant. On the other hand, severe and serious lack and shortage in potassium causes physiological symptoms such as leaves yellowing (chlorosis) and deteriorates plant growth. This element is found in four main mediums: soil solution, readily exchangeable potassium, slowly exchangeable potassium, and structural potassium bound to soil minerals. Soil solution is the direct source of potassium available for plant uptake, but it represents a very small percentage of the total potassium in the soil. Therefore, its continued availability depends on its replenishment from exchangeable and slow-exchange potassium. Structural potassium bound to soil minerals constitutes the largest proportion of the total potassium in the soil (90–98%), but its release rate is very slow (Römheld and Kirkby, 2010).

Humic matter, particularly humic acid, is important components of soil organic matter. They contribute to improving the physical, chemical, and biological properties of the soil, such as improving soil structure, increasing its water retention capacity, and enhancing the activity of microorganisms. Humic acid also acts as a nutrient complex, increasing the availability of nutrients to plants. Humic substances help convert nutrients from unavailable forms to absorbable forms and contribute to the release of phosphorus bound to iron or aluminum in acidic soils and to calcium in calcareous soils, thus increasing their availability to plants. Furthermore, humic acid can form complexes with many minerals, such as sodium, potassium, zinc, iron, and copper, which help reduce nutrient deficiencies and improve plant growth (Canellas and Olivares, 2014).

On the other hand, soil salinity is considers as one of the most significant challenges facing agricultural production in all over the world, affecting more than 20% of agricultural land and covering approximately 954 million hectares of land. High salt concentrations in the soil or irrigation water lead to osmotic and ionic stresses that negatively affected plant physiological processes, such as photosynthesis, stomatal closure, and reduced leaf growth. Furthermore, high sodium (Na^+) ion concentrations decrease the absorption of essential nutrients like calcium (Ca^{2+}) and potassium (K^+), consequently reduced plant growth and plant productivity.

While numerous studies have examined the effects of humic acid and mineral fertilization on improving plant growth, information regarding the complementary effects of humic acid and potassium fertilization on wheat (*Triticum aestivum* L.) growth under saline stress conditions remains limited, particularly in calcareous soils prevalent in arid and semi-arid regions. Therefore, this study aims to evaluate the effect of locally produced humic acid and potassium fertilization on improving nutrient availability and promoting the growth of wheat plants (*Triticum aestivum* L.) (Tahir Javaid et al., 2019).

The research also aims to determine the effect of water salinity, potassium fertilizer, humic acid, and their interaction with soluble calcium, soil pH, and wheat plant height.

III. Materials and Methods

1-2 Experiment Site and Soil Preparation for Planting

A potting experiment was conducted in one of the fields belonging to the Department of Soil Science and Water Resources, University of Sumer, Dhi Qar Governorate, during the autumn season of 2025. Plastic pots with a capacity of 25 kg of soil, a diameter of 0.32 m at the top and 0.20 m at the bottom, and a height of 0.32 m were used. Filter paper and gravel were placed at the bottom of the pot, and 20 kg of soil were added for all treatments. Soil samples were taken from each and passed through a 2 mm sieve for chemical and physical analyses before planting (Table 1). For the first factor, irrigation water salinity was applied at three levels (1, 2, 3, and 6 dS.m⁻¹), represented with the samples S1, S2, and S3, respectively. For the second factor, potassium fertilizer was applied at two levels (150 and 250 kg K ha⁻¹), represented with the samples K1 and K2, respectively. For the third factor, humic acid was applied using different methods: soil addition (HT), foliar addition (HF), combined addition (HFT), and no addition (H0). The quantity was divided among three growth stages: branching, elongation, and flowering. The wheat seeds were planted on November 15th, 2025, according to the RCBD design was used; the dissolved calcium ions, soil pH, and plant height were measured at the end of the experiment (harvest stage).

2-2 Some Chemical and Physical Analyses of Agricultural Soil.

1-2-2 Soil pH.

The pH of the soil was determined in a 1:1 soil:water extract using a pH meter according to the method described in Page et al. (1982).

2-2-2 Soluble Cations and Anions

The soluble positive and negative ions were determined according to the methods described in Page et al. (1982).

3-2 Measuring Plant Height (cm)

The average height of two plants from each experimental unit was calculated from the soil surface to the tip of the spikelet of the main branch, excluding the awns, using a measuring tape (Wiersma et al., 1986).

2-4 Preparing Irrigation Water Quality.

Water was brought from the East Al-Gharraf (salty) drain in Dhi Qar Governorate / Al-Rifai District, where the salinity of the drain water was 16 dS.m⁻¹. Then it was transferred to the experimental site, the salinity of the experimental water was obtained using the following equation (FAO, 1985):

Mixing water concentration = (River water concentration × Part of river water used) + (Drainage water concentration × Part of drainage water used). The electrical conductivity is in dS.m⁻¹ as in Table (2).

Table (1) Some chemical and physical properties of the soil under study.

Characteristics		Value	unit
Soil pH		7.2	–
Electrical conductivity (EC)		2.1	dS.m ⁻¹
Cationic ion exchange capacity		12.8	centimol charge kg ⁻¹ /soil
Organic matter		8.3	g kg ⁻¹ /soil
Dissolved ions	Positive	Ca ²⁺	5.5
		Mg ²⁺	3.1
		Na ⁺	17.8
		K ⁺	0.9
	Negative	CO ₃ ²⁻	...
		HCO ₃ ⁻	10.8
		SO ₄ ²⁻	16.00
		Cl ⁻	10.6
Available elements	Available nitrogen	127.6	mg/kg ⁻¹ /soil
	Available phosphorus	33.7	
	Available potassium	70.3	
Soil separators	sand	256.2	g/kg-1 /soil
	silt	374.7	
	Clay	369.1	
Soil texture		Silty clay loam	
Saturation percentage		43	%
Volumetric moisture content	33 kilopascal	0.30	cm ³ cm ³
	1500 kilopascal	0.10	

Available water	0.20	
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Table (2) Some chemical properties of the water used.

	unit	River water	EC3 Mixed water	Mixed water EC6
Electrical conductivity	dS.m ⁻¹	1.6	3.5	6
PH	7.5	7.3	7.2
Sodium	millimoles/liter	13.44	17.65	26.87
Calcium	millimoles/liter	5.98	5.08	7.54
Magnesium	millimoles/liter	2.66	13.15	23.65
Potassium	millimoles/liter	0.54	1.30	1.86

IV. 3- Results and Discussion

Table (3) shows that irrigation water salinity has a significant effect on the soluble calcium content in the soil. The highest level of soluble calcium was recorded at treatment S1, reaching 6.62 mmol kg⁻¹ /soil compared to treatment S3, which recorded the lowest value of soluble calcium at 6.12 mmol kg⁻¹ /soil. This is attributed to the fact that increased salt concentration in the soil leads to osmotic and ionic stress in the plant, reducing water and nutrient absorption and affecting plant physiological processes. Furthermore, high concentrations of sodium and chloride ions directly compete with the absorption of essential elements such as potassium and calcium in the soil (Xie et al., 2022). It is also observed that the addition of potassium fertilizer has no significant effect on the concentration of soluble calcium ions in the soil. The results showed that the addition of humic acid to the soil significantly affected the values of soluble calcium in the soil, as the addition of HFT was superior, with a value of 6.55 mmol kg⁻¹ /soil, compared to the treatment without addition, H0, which was 5.92 mmol kg⁻¹ /soil, with an increase of 2.10%.

The results of the bilateral interaction between salinity and potassium showed a significant effect on soil soluble calcium values. Treatment S1K2 resulted in the highest increase in soluble calcium concentration, reaching 6.65 mmol kg⁻¹ /soil, while the lowest value was observed in treatment S3K2, reaching 6.10 mmol kg⁻¹ /soil. A bilateral interaction between irrigation water salinity and humic acid was also observed, with the highest value in treatment S1HFT, reaching 7.05 mmol kg⁻¹ /soil, and the lowest value in S3H0, reaching 5.66 mmol kg⁻¹ /soil. This is attributed to the fact that humic acid can be used as a soil amendment, as it improves the physical, chemical, and biological properties of the soil. Its use in saline soils led to a decrease in electrical conductivity, improved soil structure and physical properties, and enhanced availability of nutrients such as calcium, magnesium, potassium, and phosphorus in the soil (Ennab et al., 2023). As for the interaction between potassium and humic acid, the highest value was in the K1HFT treatment, reaching 6.61 mmol kg⁻¹ /soil, and the lowest value was in the K1H0 treatment.

The tertiary interaction between irrigation water salinity levels, potassium fertilizer, and humic acid has a significant effect on the concentration of soluble calcium in the soil. Treatment S1K1HFT gave the highest values of 7.06 mmol kg⁻¹ /soil, while the lowest value was in treatment S3K1H0 mmol kg⁻¹ /soil. This is attributed to the fact that the presence of humic acid with salinity and potassium fertilization leads to maintaining a higher and more stable level of soluble calcium, as it leads to a temporary increase in the concentration of calcium in the soil solution as a result of ion displacement and in promoting the release of calcium from exchange sites, forming stable complexes with calcium and preventing its precipitation, as well as improving the cation exchange capacity (Abbas et al, 2022).

Table 3 Effect of irrigation water salinity, potassium fertilizer and humic acid on the percentage of soluble calcium in the soil (mmol kg⁻¹ /soil).

salinity	Potassium kg ha ⁻¹	Humic acid				S*K	
		H0	HT	HF	HFT		
S ₁	K ₁	6.26	6.20	6.83	7.06	6.59	
	K ₂	6.53	6.03	7.00	7.03	6.65	
S ₂	K ₁	5.93	6.23	6.10	6.43	6.17	
	K ₂	5.95	6.20	6.30	6.33	6.19	
S ₃	K ₁	5.60	6.16	6.40	6.46	6.15	
	K ₂	5.73	6.10	6.20	6.33	6.10	
(LSD) _{S*K*H}		0.33				0.16	LSD _{0.05}
humic acid (Average)		5.92	6.16	6.48	6.55		
LSD _{0.05}		0.13					
S*H							
	H0	HT	HF	HFT	Salinity (average)		
S ₁	6.40	6.11	6.91	7.05	6.62		
S ₂	5.71	6.23	6.27	6.20	6.09		
S ₃	5.66	6.13	6.31	6.40	6.12		
LSD _{0.05}	0.23				0.11	LSD _{0.05}	
K*H							
Potassium (K)	H0	HT	HF	HFT	Potassium (average)		

K₁	5.93	6.17	6.44	6.61	6.29
K₂	6.48	6.52	6.14	5.96	6.27
LSD_{0.05}	0.19			Nil	LSD_{0.05}

Table (4) shows that irrigation water salinity has a significant effect on soil pH. The highest soil pH level was recorded at treatment S3, reaching 7.68, compared to the lowest at treatment S1, which recorded a value of 11.7. This is attributed to the increase in soil pH with increasing irrigation water salinity due to the accumulation of basic salts, especially sodium salts, in the soil solution and on the exchange complex. A higher soil pH leads to an increased concentration of basic cations (Na⁺, Ca²⁺, Mg²⁺), which replace hydrogen ions (H⁺) at the exchange sites, thus reducing soil acidity and raising the pH. Furthermore, the high sodium content contributes to the formation of an alkaline environment as a result of hydrolysis reactions that produce hydroxide ions (OH⁻). Consequently, soil alkalinity increases with increasing salinity, especially in arid and semi-arid soils (Brady, 2017). We also note that the addition of potassium fertilizer has no significant effect on soil pH values. The addition of humic acid to the soil had a significant effect on the soil reaction rate values, as the combined soil and foliar addition (HFT) was superior, reaching a value of 7.44 over the foliar addition (HF) treatment, which reached 7.33.

The results of the bi- interaction between irrigation water salinity and potassium showed a significant effect on pH values, with the highest value recorded in treatment S3K2 at 7.87, compared to treatment S1K1 at 7.10. This is attributed to the combined effect on cation balance and ion exchange processes. Irrigation water salinity leads to increased accumulation of sodium and basic cations, raising soil pH, while potassium competes with sodium for exchange sites, partially limiting the increase in alkalinity. However, the continued rise in salinity maintains the overall trend towards increasing pH, making the combined effect a less pronounced increase in the degree of reaction compared to the effect of salinity alone under certain conditions (Brady, 2017).

A significant interaction effect was observed between irrigation water salinity and humic acid on soil pH, with the highest pH value (8.03) observed in the S1H0 treatment. Similarly, the interaction between potassium and humic acid resulted in the highest pH value (7.44) in the K1H0 treatment. The Triple interference between salinity of the irrigation water, potassium fertilizer, and humic acid also significantly impacted soil pH. The highest value of the soil pH (7.03) was recorded in the S3K2H0 (soil addition), while the lowest pH value (7.03) was observed in the S1K1HFT (combined foliar and soil addition). This is due to the dominant alkaline effect of soluble salts, particularly Na, which displaces hydrogen (H) ions from the exchange solution complex and increases soil alkalinity. Furthermore, the addition of potassium promotes the accumulation of basic cations and increases the intensity of cation exchange, thus contributing to a decrease in soil pH. The use of potassium humate may also provide an additional source of basic cations, further reinforcing the overall trend toward increasing soil pH. These results and findings are agree and consistent with recent studies indicating that the effect of humic substances in saline soils depends on salinity intensity and ion composition, and may lead to soil pH stabilization or even an increase rather than a decrease under certain conditions (Moro, et al., 2025).

Table 4: Effects of salinity of the irrigation water, potassium fertilizer, and humic acid on soil pH.

Salinity	Potassium Kg. ha ⁻¹	Humic acid				S*K	
		H0	HT	HF	HFT		
S ₁	K ₁	7.20	7.06	7.10	7.03	7.10	
	K ₂	7.13	7.03	7.24	7.10	7.12	
S ₂	K ₁	7.13	7.10	7.09	7.15	7.13	
	K ₂	7.13	7.26	7.10	7.20	7.17	
S ₃	K ₁	8.00	7.90	7.83	7.77	7.85	
	K ₂	8.06	7.86	7.80	7.64	7.87	
(LSD) _{S*K*H}		0.19				0.09	LSD _{0.05}
Humic acid (average)		7.42	7.35	7.33	7.44		
LSD _{0.05}		0.078					
S*H							
		H0	HT	HF	HFT	Salinity (average)	
S ₁		7.16	7.05	7.18	7.06	7.11	
S ₂		7.08	7.11	7.01	7.56	7.19	
S ₃		8.03	7.90	7.81	7.70	7.86	
LSD _{0.05}		0.13			0.06		LSD _{0.05}

K*H						
Potassium (K)	H0	HT	HF	HFT	Potassium (average)	
K ₁	7.41	7.32	7.28	7.25	7.31	
K ₂	7.44	7.38	7.38	7.63	7.46	
LSD 0.05	0.11				Nil	LSD 0.05

Table (5) shows that the irrigation water salinity plays a main role and has a significant effect on plant height, with the highest average height recorded at treatment S1, with a value of 67.58 cm, while treatment S3 recorded the lowest average of plant height reached 64.08 cm. Potassium fertilizer also had a significant effect on average plant height, with the highest average plant height recorded at K2, with 67.61 cm, representing a 2.05% increase over K1, which recorded the lowest average height which was 64.30 cm. This is due to the main role of potassium in enhancing plant physiological efficiency, as it regulates osmotic potential and maintains cell swelling, thus supporting cell elongation and increasing longitudinal growth. Potassium also plays a key role in activating more than 60 enzymes involved in photosynthesis and protein synthesis, as well as improving water use efficiency. Furthermore, potassium contributes to enhancing carbohydrate transport from leaves to growing tissues, thus supporting vegetative growth and increasing plant height, especially under stress conditions such as salinity, where it helps maintain ionic balance and reduce the toxic effects of sodium (Zörb et al., 2014). A significant effect on average plant height was observed with the addition of humic acid. The HFT treatment recorded an average plant height of 66.89 cm, an increase of 2.04%, which is not significantly different from the other additions methods compared to the no-addition H0 treatment, which recorded the lowest average height of 64.17 cm. The increase in average plant height is attributed to the direct effects on improving the physical, chemical, and biological properties of the soil, as well as its physiological effect within the plant. It increases cell membrane permeability and stimulates nutrient absorption, especially nitrogen and potassium, thus promoting vegetative growth. Humic acid also contributes to the activation of cell division and elongation through its effect similar to plant hormones. Humic also improves soil structure, aeration and water retention, providing a suitable environment for root growth (Canellas and Olivares, 2014).

The results of the binary interaction between irrigation water salinity and potassium had a significant effect on the average plant height, with the highest value recorded at S2K1 at 69.67 cm and the lowest value recorded at S3K2. Similarly, a significant effect on the average plant height was observed in the binary interaction between irrigation water salinity and humic acid, with the highest average plant height recorded at treatment S1HF at 69.00 cm, while treatments S2H0 and S3H0 recorded the lowest average plant height at 63.33 cm. This is attributed to the fact that increased irrigation water salinity led to a decrease in plant height due to osmotic stress and ion toxicity, and the addition of humic acid helped to mitigate these negative effects, as it worked to improve the root environment and increase the efficiency of water and nutrient absorption. It also helped regulate the ionic balance within the plant by reducing sodium absorption and increasing potassium absorption, which positively impacted cell division and elongation processes. Humic acid plays a main role in reducing the negative effect and damage caused by salt stress (Munns and Tester, 2008). The interaction between potassium fertilizer and humic acid also had a significant effect, with the highest average plant height recorded in K2HFT, reaching 69.56 cm. The triple interaction between irrigation water salinity levels, potassium fertilizer, and humic acid also showed a significant effect, with the highest average plant height recorded in S1K1HF, with a value of 70.67 cm, while treatment S3K2HT recorded the lowest average plant height, with 61.00 cm. This is attributed to the complementary role of both potassium and humic acid

in improving ionic balance, increasing absorption efficiency, and reducing the negative effects of salt stress (Abbas et al., 2022).

Table 5. Effect of irrigation water salinity, potassium fertilizer and humic acid on plant height cm.

Salinity	Potassium Kg. ha ⁻¹	Humic acid				S*K	
		H0	HT	HF	HFT		
S ₁	K ₁	65.00	68.33	70.33	70.67	68.58	
	K ₂	66.67	66.67	67.33	65.67	66.58	
S ₂	K ₁	67.00	70.00	71.33	70.33	69.67	
	K ₂	59.67	62.67	63.29	63.45	62.17	
S ₃	K ₁	64.67	67.33	64.31	68.43	66.08	
	K ₂	62.00	61.00	63.30	62.23	62.08	
(LSD) _{S*K*H}		3.27				1.64	LSD 0.05
Humic acid (average)		64.17	66.00	66.62	66.89		
LSD 0.05		1.33					
S*H							
		H0	HT	HF	HFT	Salinity (average)	
S ₁		65.83	67.50	69.00	68.00	67.58	
S ₂		63.33	66.33	67.33	66.67	65.92	
S ₃		63.33	64.17	63.83	65.00	64.08	
LSD 0.05		2.31			1.15	LSD 0.05	
K*H							

Potassium (K)	H0	HT	HF	HFT	Potassium (average)
K ₁	65.78	63.44	64.72	63.56	64.30
K ₂	67.58	68.44	64.94	69.56	67.61
LSD _{0.05}	1.89			0.94	LSD _{0.05}

4. Conclusions and Recommendations

V. Conclusions

1. It can be concluded that the salinity of the irrigation water negatively affects the chemical properties of soil and wheat plant growth by reducing calcium availability.
2. The addition of humic acid significantly improved soil chemical and physical properties by increasing calcium availability, reducing the negative effects of salinity, and enhancing nutrient dynamics.
3. Potassium fertilization played a main and important role in improving plant growth and mitigating salt stress by maintaining osmotic balance and enhancing plant physiological processes.
4. The combined treatment of potassium and humic acid showed a clear effect on improving soil properties and plant growth under saline conditions. Therefore, the integration of potassium fertilization and humic acid addition is an effective strategy for improving wheat productivity in saline soils.

VI. Recommendations

1. Integrated nutrient management (IMM) is recommended, combining potassium fertilization with humic acid addition, especially in saline environments.
2. Further studies are recommended to evaluate the long-term effects of humic substances and potassium fertilization on soil health and crop productivity under different environmental conditions.
3. Investigating interactions with other nutrients and different plant varieties is suggested to identify best agricultural practices for saline soils.

VII. References

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